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California State College
San Bernardino

DEVELOPING A CURRICULUM FOR MOTORCYCLE TECHNOLOGY

A Project Submitted to
The Faculty of the School of Education
In Partial Fulfillment of the Requirements of the Degree of
Master of Arts
in
Education: Administration of Vocational Education Option

By

Ronald L. Pardee, M.A.
San Bernardino, California
1981

APPROVED BY:

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Advisor

[Redacted Signature]

Committee Member

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DEVELOPING A CURRICULUM FOR MOTORCYCLE TECHNOLOGY

Ronald L. Pardee, M.A.

California State College, San Bernardino, 1981

Introduction

With the increased concern for energy efficient transportation, the use of motorcycles has increased to the point that there is an increased demand for service of the motorcycles already on the road. The motorcycle industry has developed motorcycles that commonly have fuel consumption rates of 50-60 MPG and the smaller models often operate at 90-100 MPG. This fuel efficiency also offers reduced exhaust emissions as compared to other forms of transportation.

At this time, there are more than three times the number of motorcycles in service, per mechanic, as there are in the auto industry.¹ With this increased demand for service, there has come an increase in demand for training. Many educational institutions are considering the implementation of new programs, but find it difficult to locate acceptable curriculum materials. Therefore, many programs are operating using materials that cannot meet the standards of the industry. This is made apparent by one of the major motorcycle manufacturers in offering an intensive one week school for instructors of motorcycle technology. During the months

¹ ¹Interview with Tom Anderson, American Honda Motor Co. Inc., Gardena, California, 4 August 1978.

of July and August, 1980 more than 450 secondary and post secondary instructors attended this program. The 1981 program was expanded to accomodate more instructors and offer even more in-depth training.

This project intends to address the problem of lack of good curriculum material by developing a model curriculum package that is designed specifically for the motorcycle industry, and the training of motorcycle mechanics. The original concept of this project was to outline a complete and comprehensive motorcycle technology program, but through the recommendations of educators in this field, it was decided that a model that could be used as a pattern for each subject area would be of greater value.

Review of Related Literature

The materials that were reviewed for this project were:

Mid-America Vocational Curriculum Consortium, Curriculum

American Motorcycle Schools, Curriculum

Riverside City College, Curriculum

Major Motorcycle Manufacturers, Curriculum, needs, and texts

Educational support facilities

Motorcycle Technology textbooks

Training materials presently in use by the major manufacturers

Through this review of materials, it became even more apparent that a good curriculum for Motorcycle Technology does not exist. The most predominant format for teaching this subject matter is a list of topics to be covered. The objectives, activities, information to be specifically covered, and evaluation are all left to the discretion

of the individual instructor.

This model will provide a format that can easily be followed to improve the existing curriculum.

Statement of Objectives

The objective of this project is to develop a curriculum model for a Motorcycle Technology program. This guide will use those suitable aspects from the appropriate curriculum development resources as well as be topically accurate. It will include: suggested activities, information package, student assignments, evaluation instruments, evaluation keys, laboratory exercises, resource samples and transparencies.

Design of the Product

The product of this project is a model for the development of further curriculum materials. The format of this model is arranged as follows:

- I. Unit Description
- II. Unit Overview
- III. Unit Objectives
- IV. Instructional Analysis
- V. Recommended Tools and Equipment
- VI. Specific Objectives
- VII. Suggested Activities

- VIII. Information Package
- IX. Assignment Sheets
- X. Job Sheets
- XI. Competency Sheet
- XII. Evaluation Instrument
- XIII. Evaluation Instrument Key

MOTORCYCLE TECHNOLOGY

FUNDAMENTALS

OF

ENGINE BALANCING

I. Unit Description

In this unit, students acquire knowledge and comprehension of the fundamentals of engine balancing and apply, analyze, and evaluate their experiences as related to motorcycle engine rebuilding. This unit is designed to provide cognitive and psychomotor experiences in the areas of single and multi-cylinder engine balancing. Broad topical areas include: internal and external forces found in motorcycle engines, bore and stroke relationships, multi-cylinder configurations, and designs to improve balancing.

II. Unit Overview

This unit is one of the units required for completion of the certificate program in Motorcycle Technology. The format and content of this unit were developed in consultation with several curriculum specialists, two community colleges offering similar programs, two private vocational schools, and two manufacturer training facilities.

III. Unit Objectives

On completion of this unit, the student will develop an understanding and evaluate principles in the following areas:

1. Background and Principles

Sources of Vibration

Reciprocating and Rotating Masses

Static Balancing

Primary and Secondary Forces

Bore and Stroke Ratios

Crankshaft Configurations

Couples

2. Cognitive Skills

Determining Inertia Forces

Determining Primary Forces

Determining Secondary Forces

Determining Point of Maximum Piston Velocity

Determining Direction of Rocking Couples

3. Psychomotor Skills

Crankshaft Disassembly and Inspection

Crankshaft Rebuilding

Crankshaft Truing

Establishing Reciprocating Mass

Timing of Counterbalancer Unit

Knowledge level in these areas will be evidenced through demonstration and by satisfactory performance on the written evaluation instrument.

IV. Instructional Analysis

Engine Rebuilding

-Engine Balancing

Psychomotor Skills:

What the student should be able to do (Job Training)

4. Measure stroke of an engine.
5. Measure weight of a piston assembly.
7. Measure crankshaft width.
(Use single cylinder)
8. Measure crankshaft/connecting rod radial clearance.
9. Measure crankshaft/connecting rod axial clearance.
11. Disassemble, inspect, and re-assemble a single cylinder crankshaft assembly.
12. True a single cylinder crankshaft.

Cognitive Skills:

What the student should know
(Supportive Information)

1. Identify parts of a crankshaft assembly.
2. Distinguish between a 180° twin and a 360° twin.
3. Distinguish between rotating and reciprocating parts of a crankshaft assembly.
6. Determine inertia force in a specified situation.
10. Determine appropriate axial and radial clearance for a given single cylinder crankshaft assembly.

13. Measure rod length.

14. Determine radius of crank throw.
15. Calculate the point where piston reaches maximum velocity.
16. Calculate secondary force in a specified situation.
17. Determine the direction of a rocking couple of a 180° twin with one piston at T.D.C.
18. Calculate magnitude of resultant secondary force of a 90° "V" twin.
19. Identify the direction of the rocking couples in an in-line four cylinder engine when #1 piston is at T.D.C.

V. Recommended Tools and Equipment

The following list of tools and equipment is recommended and necessary in any facility attempting to provide training or services. While this list is considered to meet minimum standards, a more complete collection can only improve the quality of work performed. Items marked with an "M" are deemed mandatory and those marked "O" can be considered optional.

SHOP EQUIPMENT & TOOLS

In the following recommendations, if the listing is preceeded by the letter M (mandatory), it is strongly recommended that the item be available. If the previx O (optional) is used, the recommendation is highly advisable but not essential.

- (M) 1. Electrical test panel (charging and electronic ignition)
Suzuki SSII
Honda
- (M) 2. V O M (Radio Shack 22-204 A)
- (M) 3. Timing tester
Buzz box
Continuity light
Strobe light (inductive)
- (M) 4. Carb sync, with adaptors
Manometer (Kawasaki, aftermarket or automotive)
Gauges (Honda)
Uni-Sync (Yamaha or aftermarket)
- (M) 5. Rotor pullers (25 - 30)
Suzuki set
K & N
Mulligan
- (O) 6. Hydrometer (M/C size, small)
- (M) 7. Dial Bore Gauge (5-150mm)
- (M) 8. Vernier Calipers
Not dial type; 0-6" and 1-150mm
(.10mm accuracy sufficient; .05mm accuracy more likely)
- (M) 9. Micrometers
0-25mm (student use)
0-25; 25-50; 50-75; 75-100mm for boring
- (M) 10. Dial indicator and magnetic base
- (M) 11. Straight edge

- (O) 12. Valve seat cutters with pilots
- (O) 13. Valve seat grinder (either #12 or #13 or both)
- (M) 14. Tap and Die set
 - I.S.O.
 - S.A.E.
 - Whitworth
- (O) 15. Helicoil sets (Keen-serts)
- (O) 16. Surface plate
- (M) 17. Service manager's desk
- (M) 18. Shop Manuals
- (O) 19. Major manufacturer's films
- (M) 20. Major manufacturer's training manuals
 - Honda
 - Electrical
 - Carburetion
 - Suzuki
 - Electrical
 - Carburetion
 - Brakes
 - Kawasaki
 - Brake systems
 - I.C. engines
 - M/C power trains
 - Carburetors
 - Exhaust systems
 - Tools and measuring instruments
 - Basic electricity
 - M/C electrical circuits
 - Frames and suspensions
 - V.O.A.
 - Metrics for Mechanics
 - S. & W. Engineering
 - Suspension Manual
 - Sudco Mikuni
- (M) 21. Repair orders (with a very strong legal liability statement)
4 copy set
- (M) 22. Air compressor (large CFM)
- (O) 23. Microfische viewer & Fische

- (M) 24. Vise
4" or 5" and 6" or 8"
- (M) 25. 6" or 7" Bench grinder
- (M) 26. Electric or air 1/4 or 3/8 inch drill
- (O) 27. Electric 1/2 inch drill
- (M) 28. Drill index (110 piece recommended)
- (M) 29. Cylinder hones
Flex hones (180 Grit)
Manderel type (both types, ideal)
- (M) 30. Crank truing stand (Rowe Mfg. H.D.)
- (M) 31. Wheel truing stand (Rowe)
- (M) 32. Spoke wrenches (Rowe, M6)
- (M) 33. Tire changer or barrel
- (M) 34. Parts washer (Safety Kleen)
- (O) 35. Pressure solvent gun
- (M) 36. Battery charger 1.5 Amp output; 6 & 12 Volt
- (M) 37. Drill press
- (M) 38. Hydraulic press
- (O) 39. Welder
 - (M) Arc
 - (M) Gas
 - (O) Heli arc
 - (O) Hot air
- (M) 40. Boring bar(s)
40-100 mm (Rotler or Kwik-Way)
- (O) 41. Lathe
Jet 1024P
- (O) 42. Read blaster
- (O) 43. Dynamometer (Road load simulator)

- (O) 44. Infrared analyzer (soon mandatory)
- (O) 45. Lifts
- (M) 46. Drain pans
- (M) 47. Oily rag can with lid
- (M) 48. Fire extinguishers
- (M) 49. Baking soda, acid neutralizer
- (M) 50. Gas cans/funnels
- (M) 51. Grease gun
- (M) 52. Silicone sealer
 - 3 Bond
 - Loctite (green, blue and red)
- (M) 53. Lubricants
 - Chain oil (o-ring and standard)
 - Assembly oil (Torco)
 - 4-Stroke
 - 2-Stroke
 - Lithium grease
 - Dri-Slide
- (M) 54. Cleaners
 - Acetone
 - Lacquer thinner
 - Contact cleaner
 - M.E.K.
- (O) 55. Engine stand(s)
- (M) 56. Special 4-Stroke tools
- (M) 57. Special 2-Stroke tools
- (O) 58. Leak Down tester (2-stroke, Pressure/Vaccum)
- (M) 59. Compression tester (with 10mm and 12mm adaptors)
- (O) 60. Leakdown tester (4-stroke)
- (O) 61. Porting grinder
- (O) 62. Valve grinder

- (O) 63. Degree wheel
- (M) 64. Valve spring compressor
- (M) 65. Ring compressors
- (M) 66. Knife edged bearing puller
- (M) 67. V Blocks
- (M) 68. Fork straightening cushion
- (M) 69. Electrical test leads
- (M) 70. Feeler gauges
wire
flat
- (O) 71. Duct tape
- (M) 72. Tire irons
- (M) 73. Tire mounting lube
- (O) 74. Rim savers
- (M) 75. Electrical crimping tool
- (M) 76. Electrical wire and terminals
- (O) 77. Publication subscriptions
Cycle News West
Dealernews
International Motorcycle Trade Journal
- (M) 78. Circlip pliers (Kawasaki)
- (M) 79. Valve guide drifts
- (M) 80. Hot plate
- (O) 81. Valve guide reamers
- (M) 82. Timing dial indicator
- (M) 83. Soldering gun
- (M) 84. Hand impact with extra tips
- (O) 85. Thread files

- (M) 86. Hacksaw
- (O) 87. Tweezers
- (M) 88. Torque wrench (not deflecting beam)
- (M) 89. 16mm deep socket
- (M) 90. 18mm deep socket
- (O) 91. 3/4 inch deep socket
- (M) 92. Oil slinger socket (not T handle)
- (M) 93. 1/2 inch air impact
- (O) 94. 3/8 inch impact (butterfly)
- (M) 95. Hand files
- (O) 96. Gas line
- (O) 97. Hose clamps
- (O) 98. Hardware (nuts and bolts)
- (M) 99. Carb cleaner
- (M) 100. Tape measure
- (M) 101. 6" scale
- (O) 102. Anti-seize
- (M) 103. Press plates
- (M) 104. Lead (brass) hammer

MOTORCYCLE MECHANIC'S BASIC TOOL LIST

In the following recommendations, if the listing is preceded by the letter M (mandatory), it is strongly recommended that the item be available. If the prefix O (optional) is used, the recommendation is highly advisable but not essential.

I. Tool Box

II. Wrenches

A. Socket Type

(M) 1. 3/8" Drive Sockets

- a. 8mm
- b. 9mm
- c. 10mm
- d. 12mm
- e. 13mm
- f. 14mm
- g. 15mm
- h. 17mm
- i. 19mm
- j. sparkplug sockets (16mm, 18mm, 3/4" and 3/16")

(M) 2. 1/2" Drive Sockets

- a. 20mm
- b. 21mm
- c. 22mm
- d. 23mm
- e. 24mm
- f. 25mm
- g. 26mm
- h. 27mm
- i. 28mm
- j. 29mm
- k. 30mm
- l. 32mm

3. 3/8" Drive Accessories

- (M) a. Ratchet
- (O) b. Spinner
- (M) c. 3" extension
- (O) d. 6" extension
- (O) e. Speed handle

- (O) f. #2 phillips screwdriver blade
- (O) g. #3 phillips screwdriver blade
- (O) h. 3/8" flat screwdriver blade
- (M) i. Torque wrench (1-20 kg/M)
- (M) j. 3/8" to 1/2" adaptor
- (M) k. Allen set
 - 4mm
 - 5mm
 - 6mm
 - 8mm
 - 10mm
 - 12mm

(M) l. Hand impact tool

4. 1/2" Drive Accessories

- (O) a. 18" breaker handle
- (M) b. 1/2" to 3/8" adaptor

(M) B. Combination (Box/open end)

- 1. 8mm
- 2. 9mm
- 3. 10mm
- 4. 12mm
- 5. 13mm
- 6. 14mm
- 7. 15mm
- 8. 17mm
- 9. 19mm
- 10. 21mm
- 11. 23mm
- 12. 24mm
- 13. 27mm
- 14. 32mm

C. Adjustable type

- (M) 1. 4"
- (O) 2. 6"
- (M) 3. 8"
- (O) 4. 12"

(M) D. Allen type set

(M) E. Spoke wrench

III. Screwdrivers

A. Phillips blade

- (M) 1. #1, 5" 50 6" blade
- (M) 2. #2, 5" tp 6" blade
- (M) 3. #3, 8" blade
- (O) 4. #2, offset

B. Flate blade

- (M) 1. 1/8", 5" to 6" blade
- (M) 2. 1/4", 5" to 6" blade
- (O) 3. 1/4", offset
- (M) 4. 3/8", 5" to 6" blade
- (O) 5. 1/2", 8" blade
- (O) 6. 3/16" to 1/4", 12" blade

IV. Pliers

- (M) A. Common slip-joint, 6" to 8"
- (M) B. Water pump, 10"
- (M) C. Needle nose, 5" to 6"
- (M) D. Duckbill, 5" to 6"
- (M) E. Diagonal wire cutters, 4" to 6"
- (M) F. Wire stripper/crimper
- (M) G. Circlip pliers
 - 1. Inside type
 - 2. Outside type
- (M) H. Vise grips, 5" and 8"

V. Punches

- (M) A. Pin type
 - 1. 1/16"
 - 2. 1/8"
 - 3. 3/16"
- (M) B. Drift pins (soft)
 - 1. 4"
 - 2. 10"
- (M) C. Cold Chisels
 - 1. 3/16"
 - 2. 1/4"
- (M) D. Center punch, 4"

VI. Hammers

A. Ball-Peen

- (O) 1. Small
- (M) 2. Medium/Large

(M) B. Plastic Mallet

(O) C. Large rubber Mallet

(M) D. Brass Mallet

VII. Tire tools

(M) A. Valve core tool

(M) B. Pressure gauge (0 to 40 psi)

(M) C. Tire levers

(O) D. Tire inflation chuck

VIII. Cutting Tools

(M) A. Hack saw

(M) B. Files

1. Medium flat mill

2. Medium half-round mill

3. Rat tail

a. small

b. medium

4. Point file (or Flex stone)

5. Thread file set

IX. Measurement instruments

(O) A. Vernier Caliper (metric and standard)

(O) B. Micrometers (metric 0.01mm accuracy or better)

1. 0-25mm

2. 25-50mm

3. 50-75mm

4. 75-100mm

(O) C. Dial bore gauge (metric, 0.01mm accuracy or better)

1. 10-18mm

2. 18-35mm

3. 35-150mm

(O) D. Small hole gauges

(O) E. Telescoping gauges

X. Miscellaneous

(M) A. Test light

(M) B. Jumper wires w/clips

(M) C. Scribe or pick

(O) D. Rolling head pry bar (lady's foot)

- (O) E. Long handled inspection mirror
- (M) F. Gasket scraper
- (M) G. Feeler gauges
 - 1. Wire (spark plug type)
 - 2. Blade (large and small ignition type)
- (O) H. Screw extractor set
- (M) I. Pocket knife
- (O) J. Case splitter (universal)
- (O) K. Magnetic pick-up
- (O) L. Flywheel puller set

VI. Specific Objectives

After completion of this unit, the student will be able to:

1. Identify the parts of a crankshaft assembly.
2. Distinguish between a 180° twin crankshaft and a 360° twin crankshaft.
3. Designate the rotating and reciprocating parts of a crankshaft.
4. Measure the stroke of an engine and weigh the piston assembly.
5. Calculate inertia forces in a given situation.
6. Determine the appropriate clearances and measure radial and axial clearances of a crankshaft assembly.
7. Disassemble, inspect, reassemble, and true a single cylinder crankshaft.
8. Measure connecting rod length.
9. Determine the radius of a crankshaft throw.
10. Calculate the point of maximum piston velocity.
11. Compute the secondary force in a given situation.
12. Identify the directions of rocking couples in 180° designs and in-line four cylinder engines.
13. Calculate the magnitude of the resultant secondary force of a 90° "V" twin.

VII. Suggested Activities

A. Instructor:

1. Provide student with unit description, overview, objective and competency sheets.
2. Provide student with information, assignment and job sheets.
3. Make transparencies.
4. Discuss unit and specific objectives.
5. Discuss psychomotor and cognitive skills sheet.
6. Discuss information and assignment sheets.
7. Demonstrate use of any tools required for completion of competencies.
8. Demonstrate and discuss the procedures outlined in the job sheet.
9. Administer written evaluation instrument.
10. Correct and review the written evaluation instrument.

B. Student:

1. Read the unit description, overview, objective and competency sheets.
2. Read and study the information, assignment and skill sheets.
3. Complete assignment and skills sheets.
4. Complete activities assigned by instructor.
5. Demonstrate proficiency in competencies.
6. Answer the questions on the evaluation instrument.

VIII. Information Package

ENGINE CRANKSHAFT BALANCE

There are two reactions felt external to the engine: output torque and unwelcome vibration from the piston and connecting rod which is the "inertia load." If there are reciprocating parts, there will be vibration. The purpose of crankshaft balancing is to reduce this vibration with forces opposing those already present (i.e. an imbalance on the crankshaft in the form of a counter weight, or external weights such as those used in Honda's 400cc twin.) (See Ill. 1 and 2).

The inertia load from the reciprocating parts is a result of the split second deceleration of the piston (and immediate acceleration in the opposite direction) at the end of each stroke.

This inertia load can be calculated and an engine designer can attempt to compensate for it and minimize the vibration. The formula used to calculate this inertia force is:

$$I.F. = (.0000142)(W)(RPM^2)(S)$$

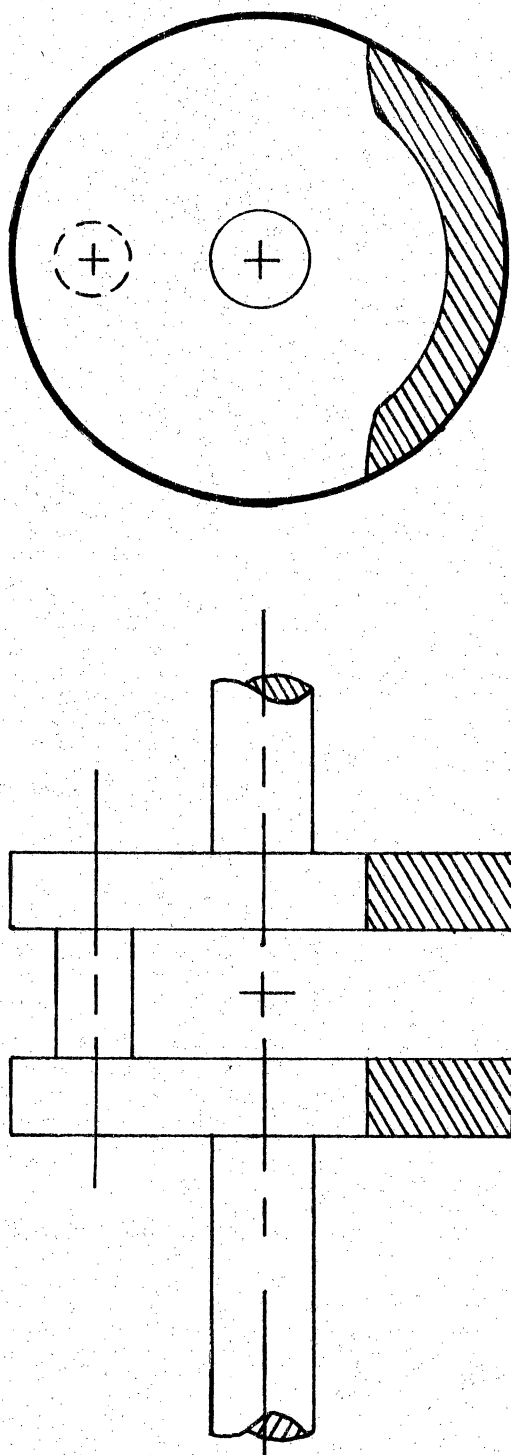
Where:

I.F. = Inertia Force = .0000142 = Constant (K)

W = weight of piston assembly measured in pounds *See Note.
(e.g. 14 oz. = .875 lb.)

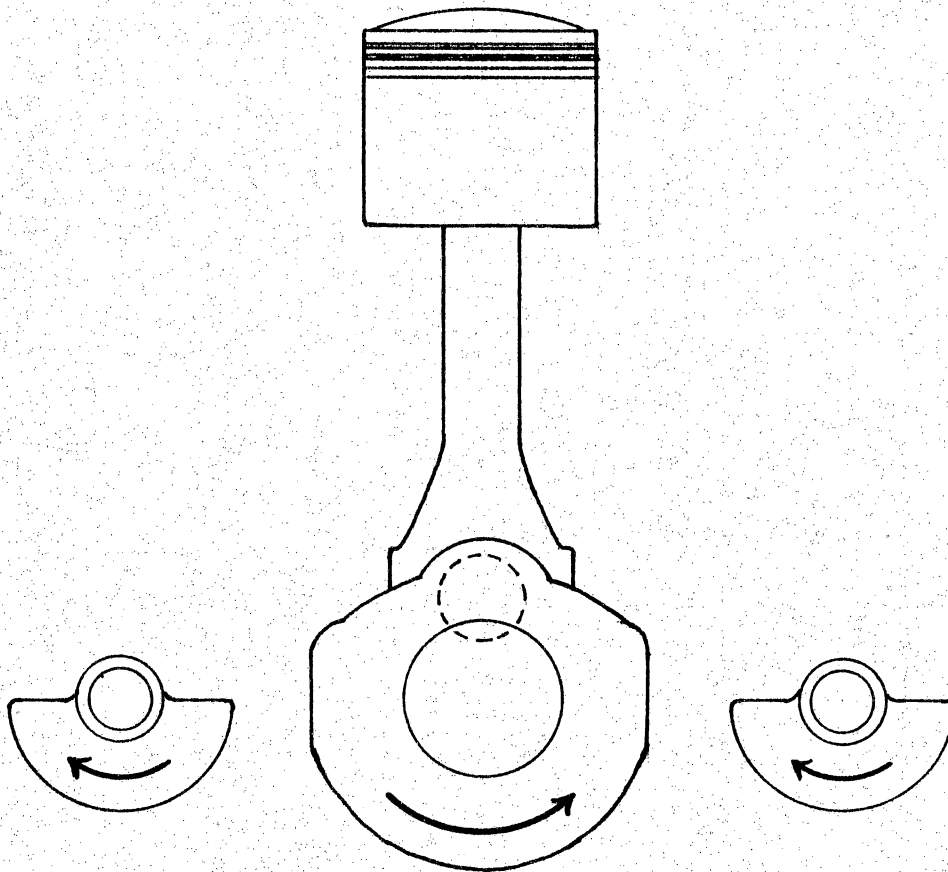
RPM² = revolutions per minute squared (i.e. RPM x RPM)

S = stroke measured in inches



ILL. 1 Front and side view of a crankshaft, shaded area represents added weight to compensate for weight of the crankpin.

ILL. 2 Side view of crankshaft with separate, chain driven counterweights.



This force is transmitted through the connecting rod to the crankshaft, through the main bearings, and to the cases. It is felt by the operator unless it is absorbed.

*Note: Piston assembly includes: Piston, wrist pin, wrist pin circlips, and the top half of the connecting rod. The rings are not considered part of the piston because they actually float during the time of high inertia loading and because of their friction against the cylinder wall. The top half of the connecting rod is considered to be a reciprocating mass and the bottom half is considered to be a rotating mass. Only the bottom half of the connecting rod is part of the crankshaft, along with the rod pin, bearing and thrust washers, where appropriate.

Various materials and styles of engine mounting have different absorption characteristics. Some frame and engine configurations isolate vibration better than others.

It will become apparent, as we continue in our diagnosis, that main bearings must also be designed to withstand specific shock loading and crankshaft distortion.

The inertia force that we have discussed can be considered the primary force in engine balancing.

Example:

Calculation of I.F. (Inertia Force)

$$I.F. = (.0000142)(W)(RPM^2)(S)$$

$$I.F. = (.0000142)(15.2 \text{ oz.})(6000 \text{ RPM}^2)(1.82 \text{ in.})$$

$$I.F. = (.0000142)(.95 \text{ lb.})(36,000,000 \text{ RPM})(1.82 \text{ in.})$$

$$I.F. = (511.2)(.95 \text{ lb.})(1.82 \text{ in.})$$

$$I.F. = (485.64)(1.82)$$

$$I.F. = (883.8648)$$

$$I.F. = 884 \text{ lbs.}$$

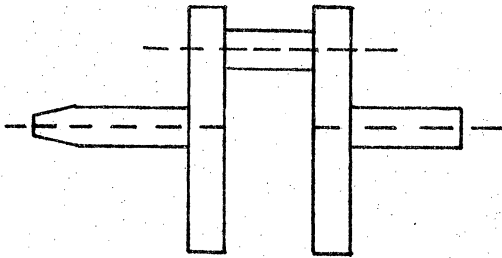
The crankshaft construction can be modified to help reduce the primary forces that are developed, but we must first insure that the crankshaft itself is balanced. The balance that we are concerned with is that the crankshaft centers are actually the center of the assembly, and that the flywheel halves are true to each other. (See Ill. 3).

If the crankshaft is balanced and supported on centers as indicated in Ill. 3A, the center of gravity will be along the same plane as the centers. If the crankshaft were rotated, there would be no heavy spots that would always rotate to the bottom because of the force of gravity.

Considerations that must be made when checking this static balance are the weight of the rod pin and the big end half of the connecting rod. Engine designers take these weights into consideration when producing the crankshaft, and either add weight to the flywheel halves on the opposite side of the flywheel from the crank pin, or remove weight from the area nearest to the crank pin. (See Ill. 4). It is important to note that the weight must be removed in equal amounts from each flywheel half, or an unbalance will exist on the horizontal plane.

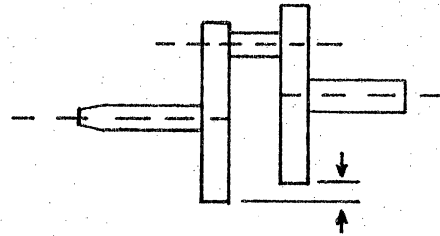
It should be apparent that it is relatively easy to balance the rotating parts of the crankshaft assembly. It is also interesting to note that if a rotating element is balanced, the RPM will not affect this balance, but any out-of-balance condition will become more noticable as RPM increases.

Ill. 3A True crankshaft

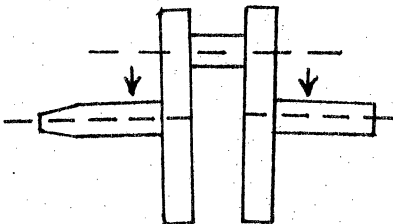


B Crankshaft that is not true.

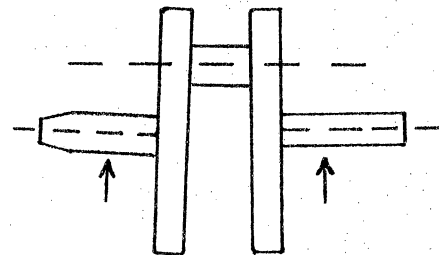
The center of each flywheel is offset.



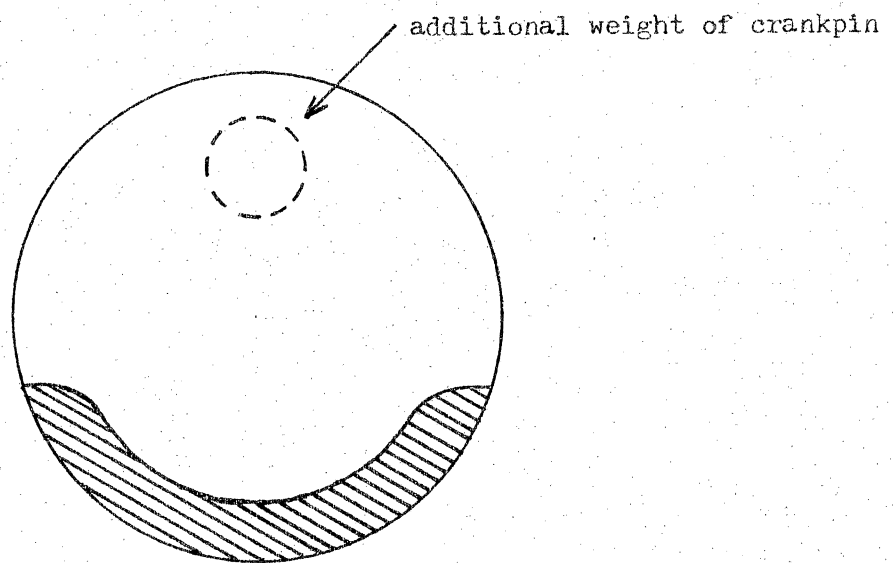
C Non-parallel crankshaft;
arrows indicate high spot



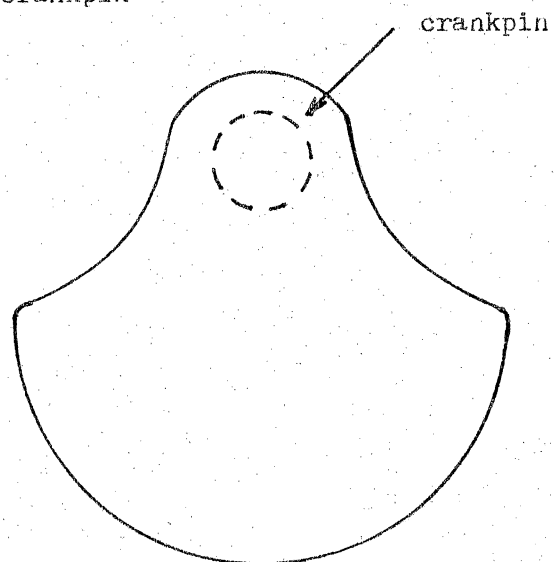
D Non-parallel crankshaft with
high spots opposite of 30.



ILL. 4A Added counter weight to offset the weight of the crankpin.



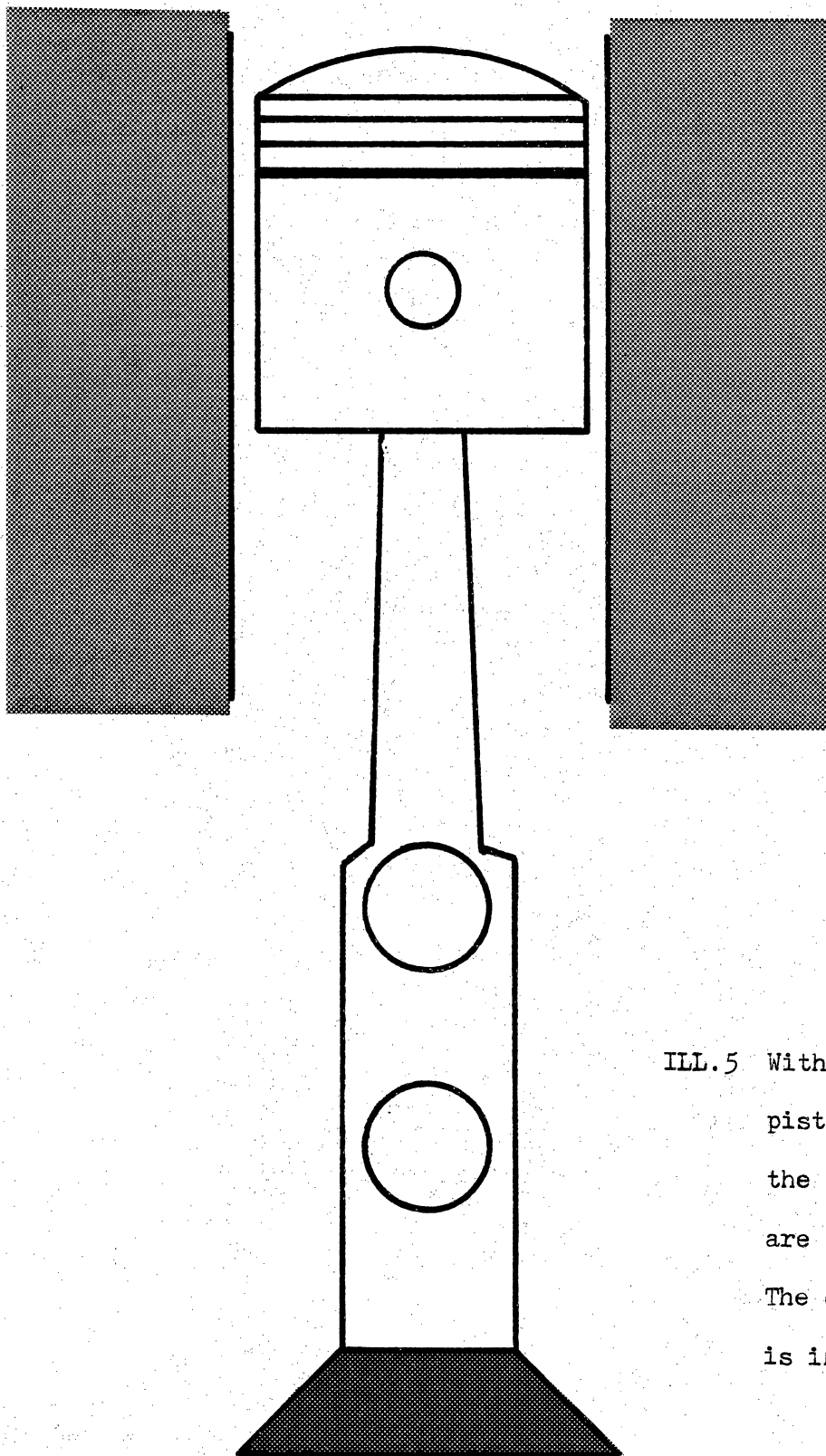
B Weight removed from the flywheel to offset the additional weight of the crankpin



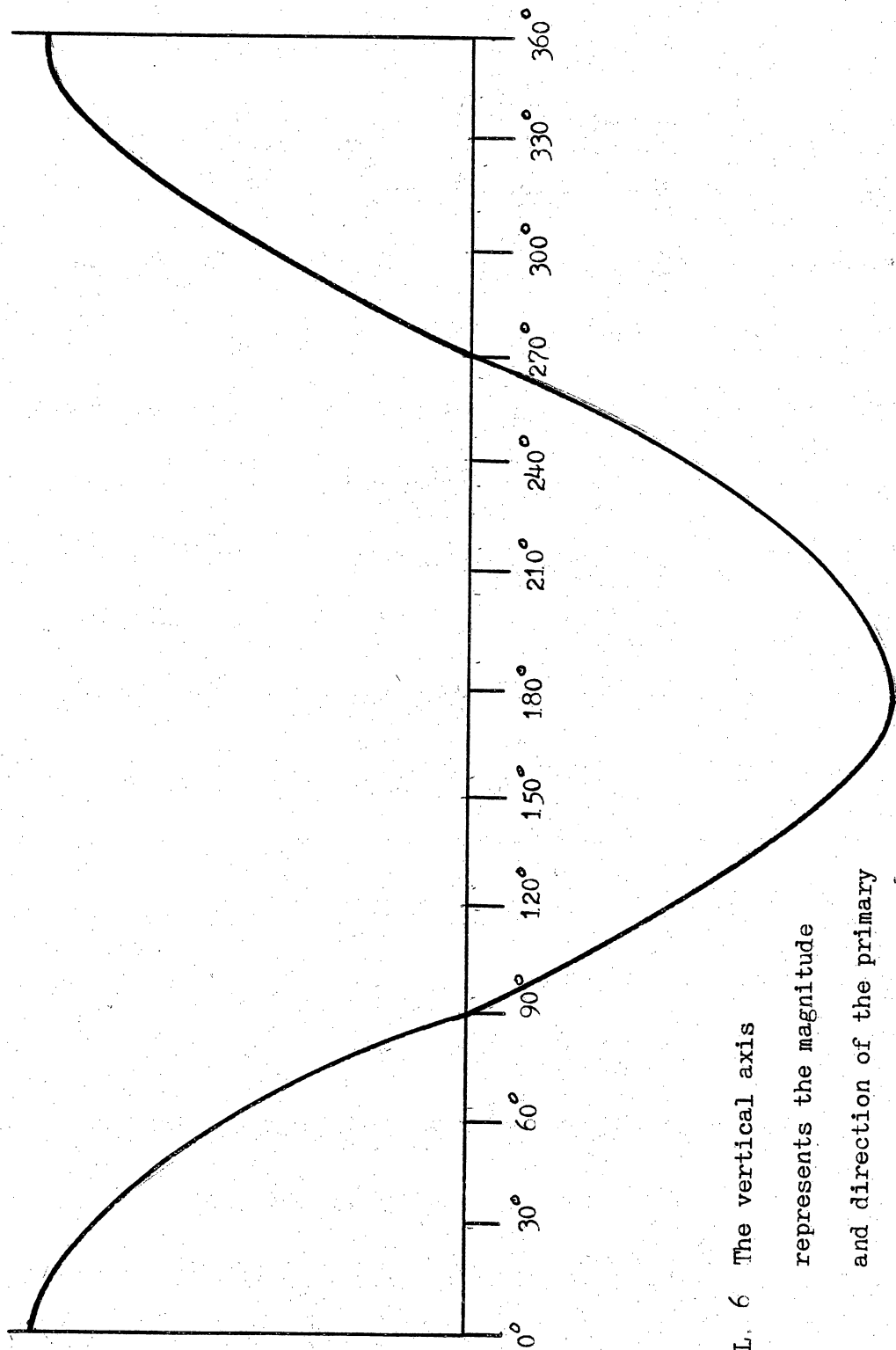
The primary force is at its greatest imbalance when the reciprocating mass changes direction, so the greatest imbalance occurs at T.D.C. and B.D.C. if the crankshaft is balanced in relation to rotating forces. (See Ill. 5). Notice that the piston velocity will be zero at this point, and the primary force will be applying tension to the connecting rod. At B.D.C., these primary forces will again be at a maximum, but the connecting rod is now in compression. Illustration 6 plots these forces on a graph and shows that the primary forces are zero at 90 degrees and 270 degrees of crankshaft rotation. This is the point where the force changes direction, so there is no inertial force from the piston assembly. Illustration 7 depicts a crankshaft assembly in this position.

It is possible to reduce the effect of the piston inertia by adding weight to the crankshaft that will exactly "balance" this force when it is at its maximum (T.D.C. and B.D.C.). (See Ill. 8). It is important to recall that the formula for determining I.F. of the reciprocating mass includes the RPM of the assembly, which indicates that this counterbalance weight would only provide the correct balance factor at the specified RPM. Engine designers take this into consideration and use a weight that will match the optimum operating RPM.

Unfortunately, this balancing problem is not as simple as it may appear. If the primary force is fully balanced at T.D.C. and B.D.C. where the piston velocity is zero, it will be fully out of balance when the piston velocity is at its maximum, at midstroke. (See Ill. 9).



ILL.5 With the piston at T.D.C. the inertia forces are their greatest. The connecting rod is in tension.



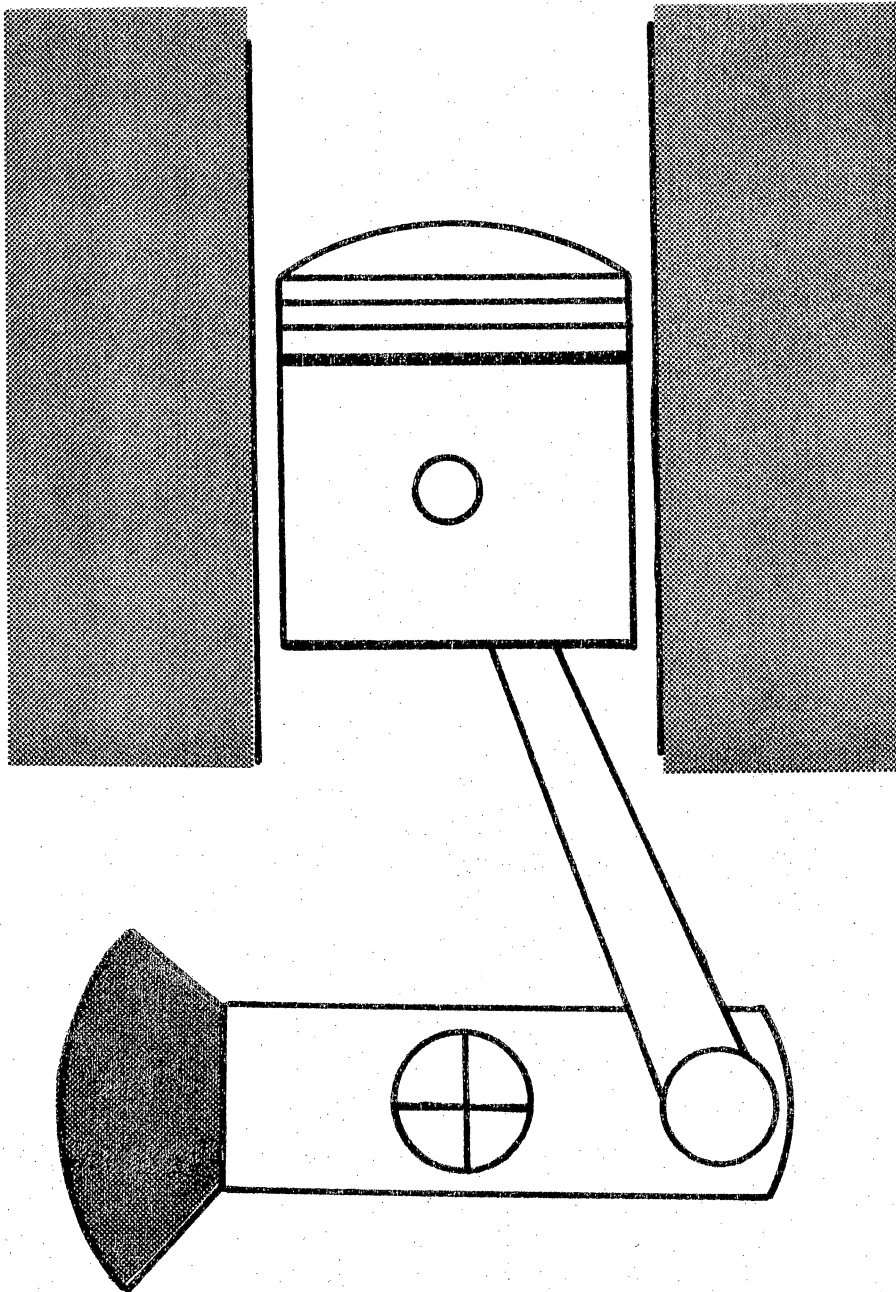
ILL. 6 The vertical axis

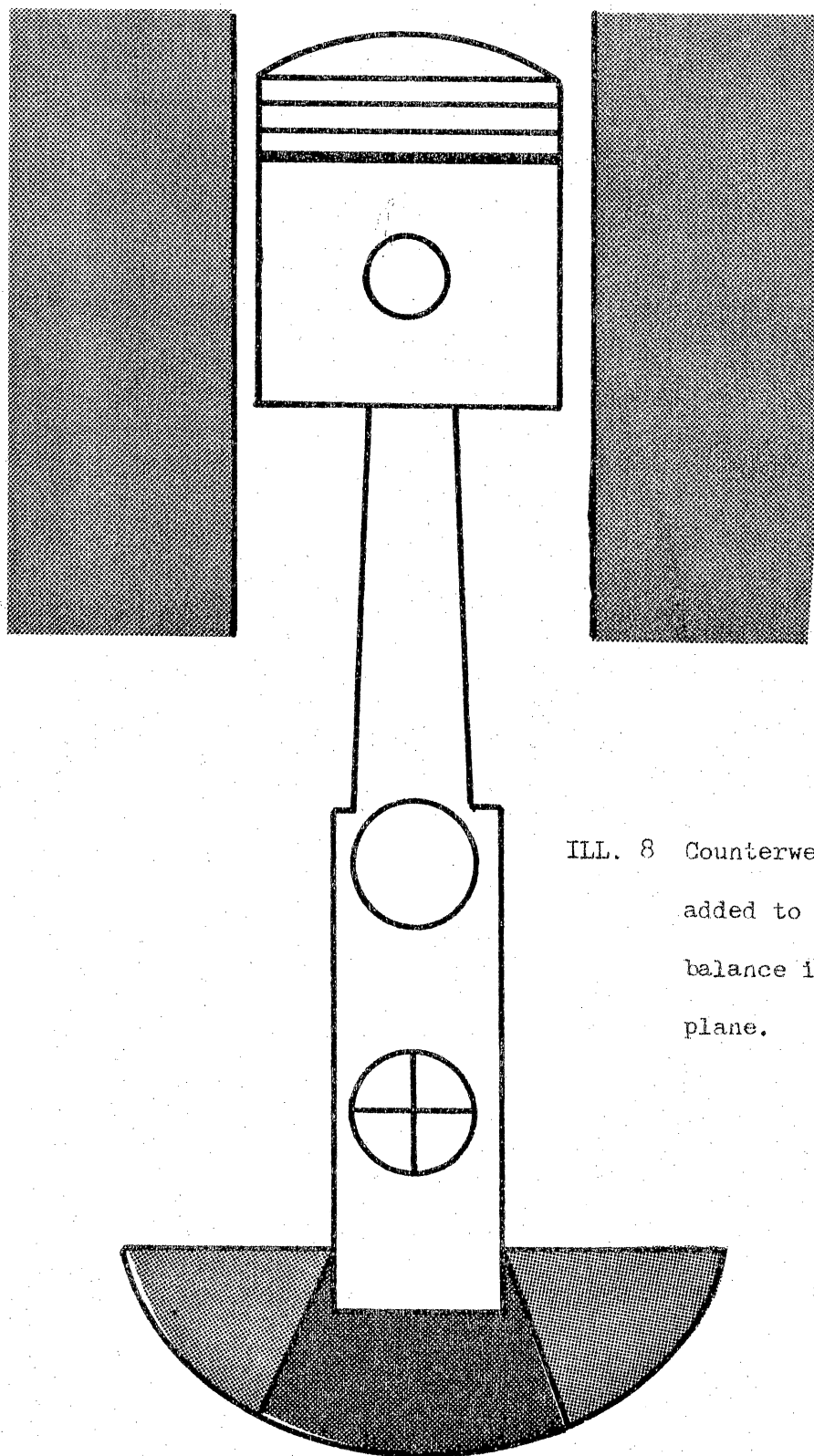
represents the magnitude

and direction of the primary

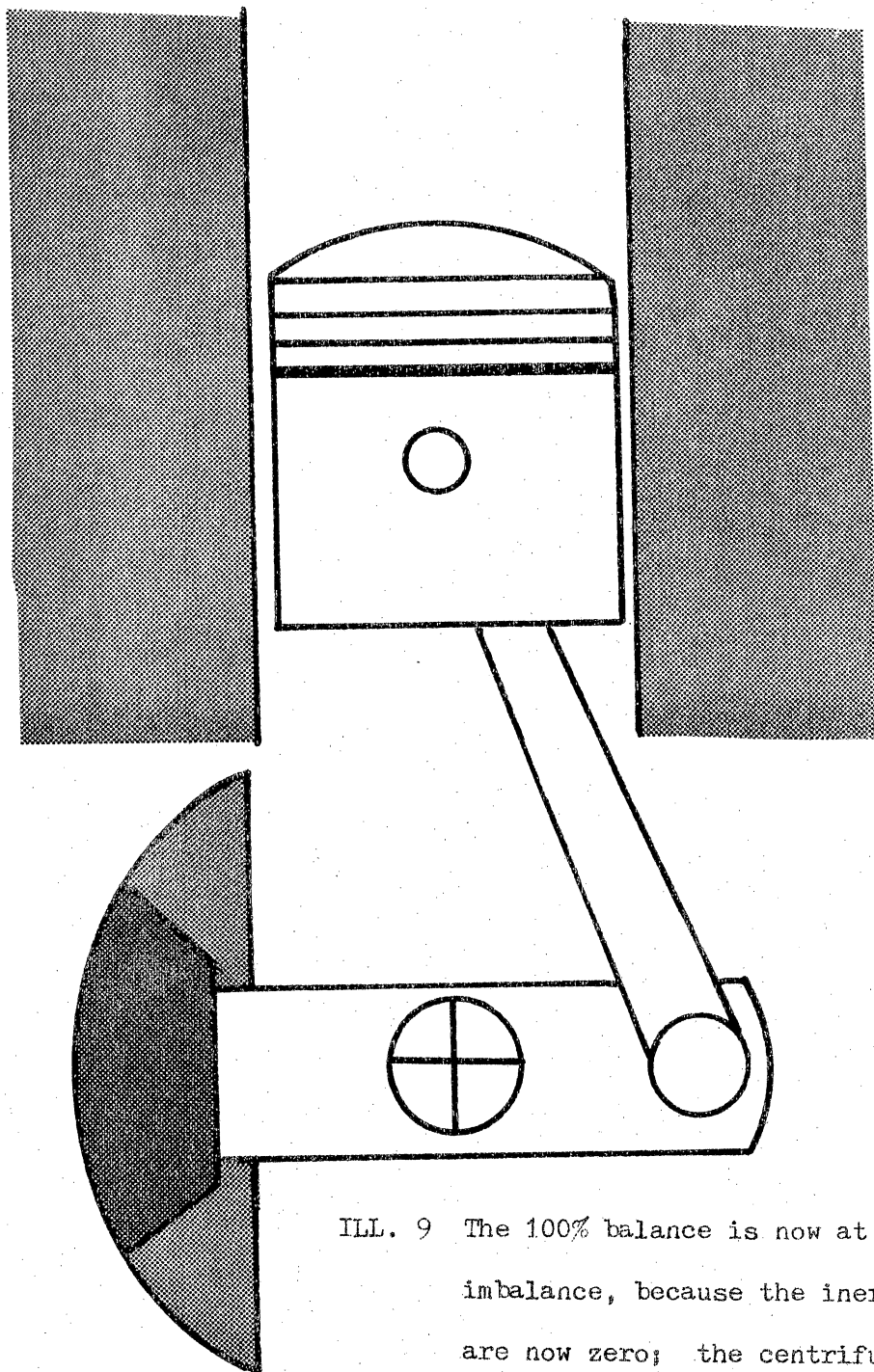
forces, relative to the crankshaft rotation, represented on the horizontal axis.

ILL. 7 With the crankshaft at midstroke, the inertia forces are zero and the centrifugal forces are at their maximum value.





ILL. 8 Counterweights are added to give 100% balance in the vertical plane.



ILL. 9 The 100% balance is now at 100%
 imbalance, because the inertia forces
 are now zero; the centrifugal forces
 cannot change in magnitude, only direction.

We may now draw the conclusion that the balancing of a simple crankshaft assembly is a trade-off between vertical and horizontal imbalance. This is illustrated by the terms applied to engine balancing. An engine with a 50% balance factor indicates that the primary forces in the vertical plane are reduced by 50%, but are out of balance by the same amount in the horizontal plane. This gives an imbalance of less magnitude and greater frequency, which is often the least objectionable to operation at the optimum RPM. The percentage, or balance factor, is the amount of reciprocating force that is transferred from the vertical plane to the horizontal plane. As this balance factor changes, it also changes the point where the maximum value of imbalance occurs relative to crankshaft rotation, or how close to the horizontal plane (90 degrees from T.D.C.) the imbalance occurs. The forces produced by the reciprocating components are always in the same plane (direction), but vary in value, while the rotating component is constant in magnitude, but varies in direction. It is therefore impossible to obtain balance when there is only one reciprocating component and one rotating component, as in a typical single cylinder engine.

It was indicated earlier that the point of maximum piston velocity occurs when the piston is at midstroke, as shown in Illustration 7. This is really only an approximation, as the point of maximum velocity will vary as the length of the stroke and/or the rod length change.

Specifically, the formula is:
$$\text{COT} = \frac{\frac{\text{Stroke}}{2}}{\text{Rod Length}}$$

Note: $\frac{\text{Stroke}}{2}$ = the radius of the crank throw, and both measurements should be taken from the centers. Illustration 10 shows where these measurements should be made.

This formula gives the cotangent of the angle created by an imaginary line from the crankshaft center to the rod pin and the line created by the stroke of the piston. At this point the rod forms a 90 degree angle with the rod pin to crankshaft center line. (See Ill. 11).

This trigonometric function (ratio of rod length to rod throw radius) allows us to establish the angle θ (Greek letter Theta) by using a set of natural trig tables where we find the angle that is the cotangent of this ratio. (See Appendix A for table of trig functions.)

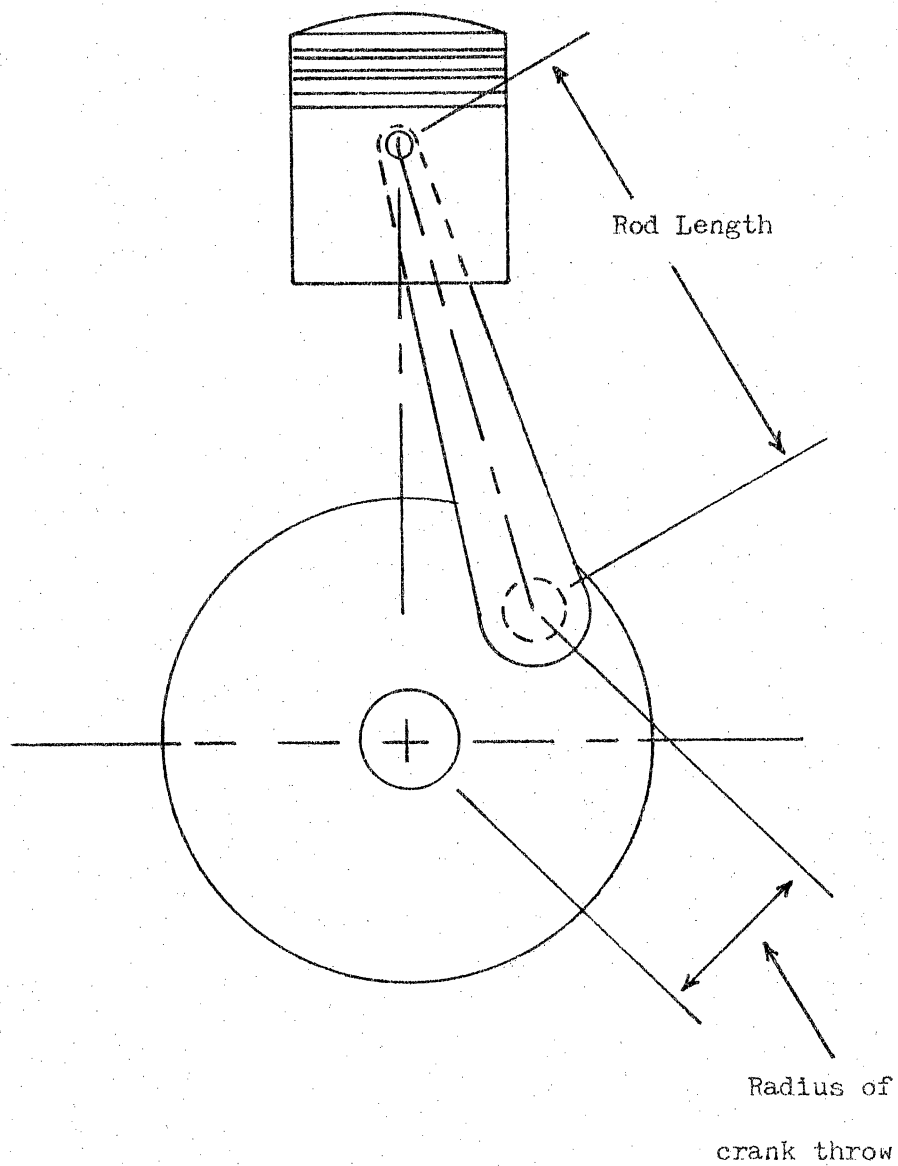
Example:

Rod length	= 4.7 inches
Radius of crank throw	= .91 inches
Ratio	= .1936
COT	= .1936 approx -- angle = 79 degrees
θ	= 79 degrees

θ is the number of degrees before or after T.D.C. when the piston reaches maximum velocity. Notice that this is not the midstroke of the piston, and it will also vary from engine to engine as the rod length and stroke change.

When considering this example with Illustration 11, one should be able to visualize that when the piston is traveling toward T.D.C., it will decelerate from maximum velocity (at 79 degrees B.T.D.C.) to zero velocity (at T.D.C.) and accelerate to maximum velocity again

ILL. 10 This indicates where to take measurements for rod length
and for the radius of the crank throw.



ILL. 11 T.D.C., B.D.C.

and mid stroke are indicated. The position of maximum piston velocity is indicated and the included angle of 148° is shown.

T.D.C.

Maximum piston
velocity

Midstroke

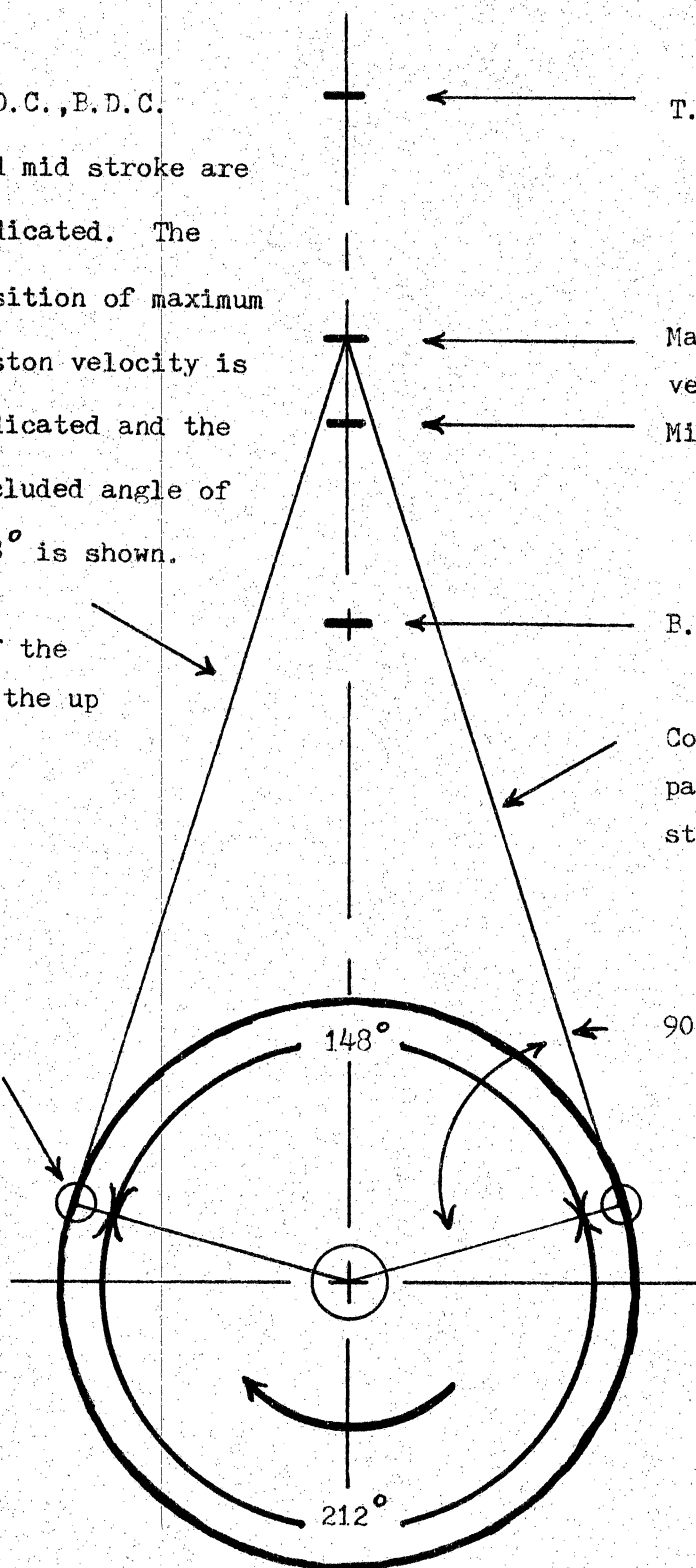
B.D.C.

Connecting rod
path on the down
stroke

Path of the
rod on the up
stroke

Crankpin

90 degrees



(at 79 degrees A.T.D.C.) in 148 degrees of crankshaft rotation. This means that the same deceleration to B.D.C. and acceleration to 101 degrees A.B.D.C. (79 degrees B.T.D.C.) takes 202 degrees of crankshaft rotation. The result is that the velocity in the upper part of the stroke is greater than in the lower part of the stroke. Since the inertia force is dependent upon velocity, the inertia force in the upper portion of the stroke is greater than in the lower portion. This difference in inertia force creates a secondary force that acts in a vertical plane at T.D.C. and B.D.C.

The magnitude of this force is represented by the formula:

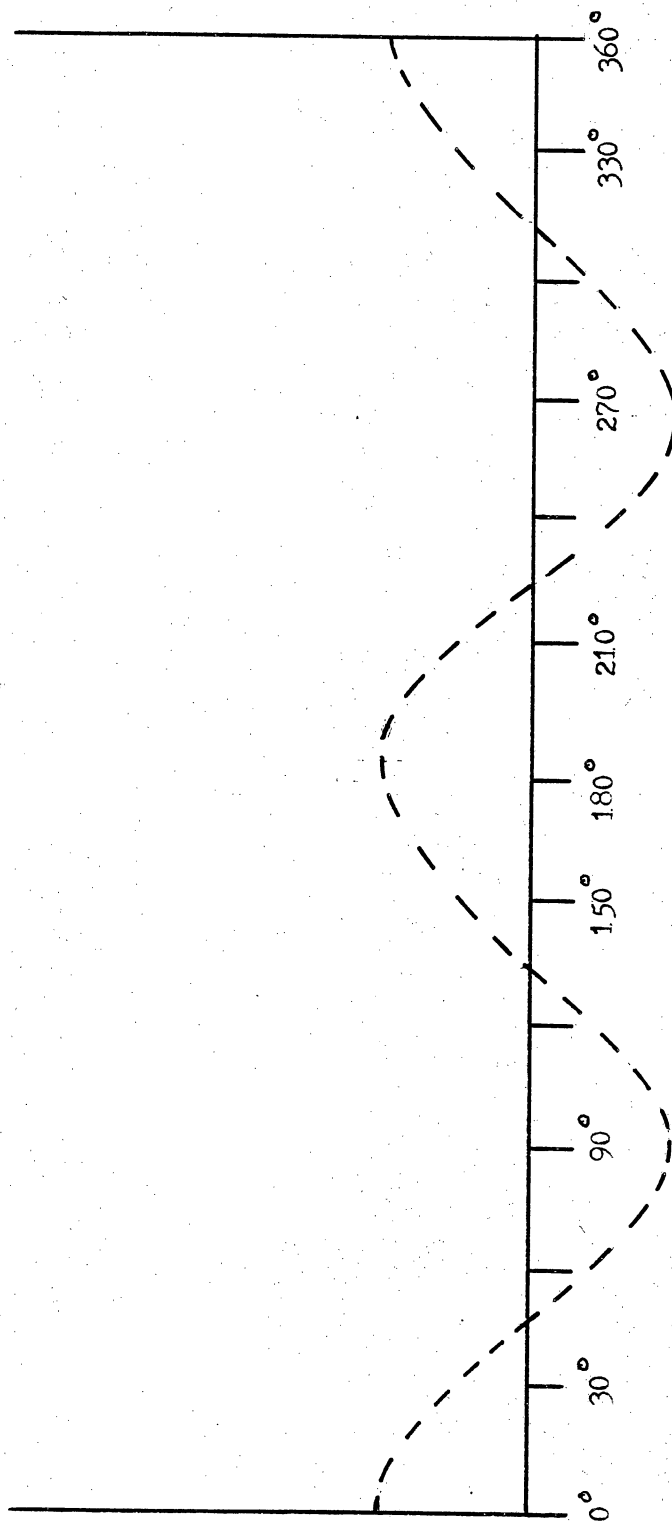
$$\text{Secondary Force} = \frac{(\text{Radius of crank throw})}{(\text{Rod Length})} (\text{Primary Forces})$$

Example:

$$\left(\frac{.91 \text{ inches}}{4.7 \text{ inches}} \right) (884 \text{ lbs.})$$

$$(1936)(884 \text{ lbs.}) = 171.1424 \text{ lbs.} = \text{Secondary Force}$$

The total inertia force applied to an engine is a combination of the primary and secondary forces. We can plot these forces on a graph similar to the one shown in Illustration 6, but we must first plot the secondary forces and graphically add the two forces. Illustration 12 represents the secondary forces. Notice that the force also follows a sinusoidal wave form, but at twice the frequency and of a smaller magnitude. Notice also that the secondary forces are at their maximum upward direction a 0 degrees, 180 degrees, and again when back at T.D.C.; they are at their maximum downward direction at 90 degrees and 270 degrees of crankshaft rotation.



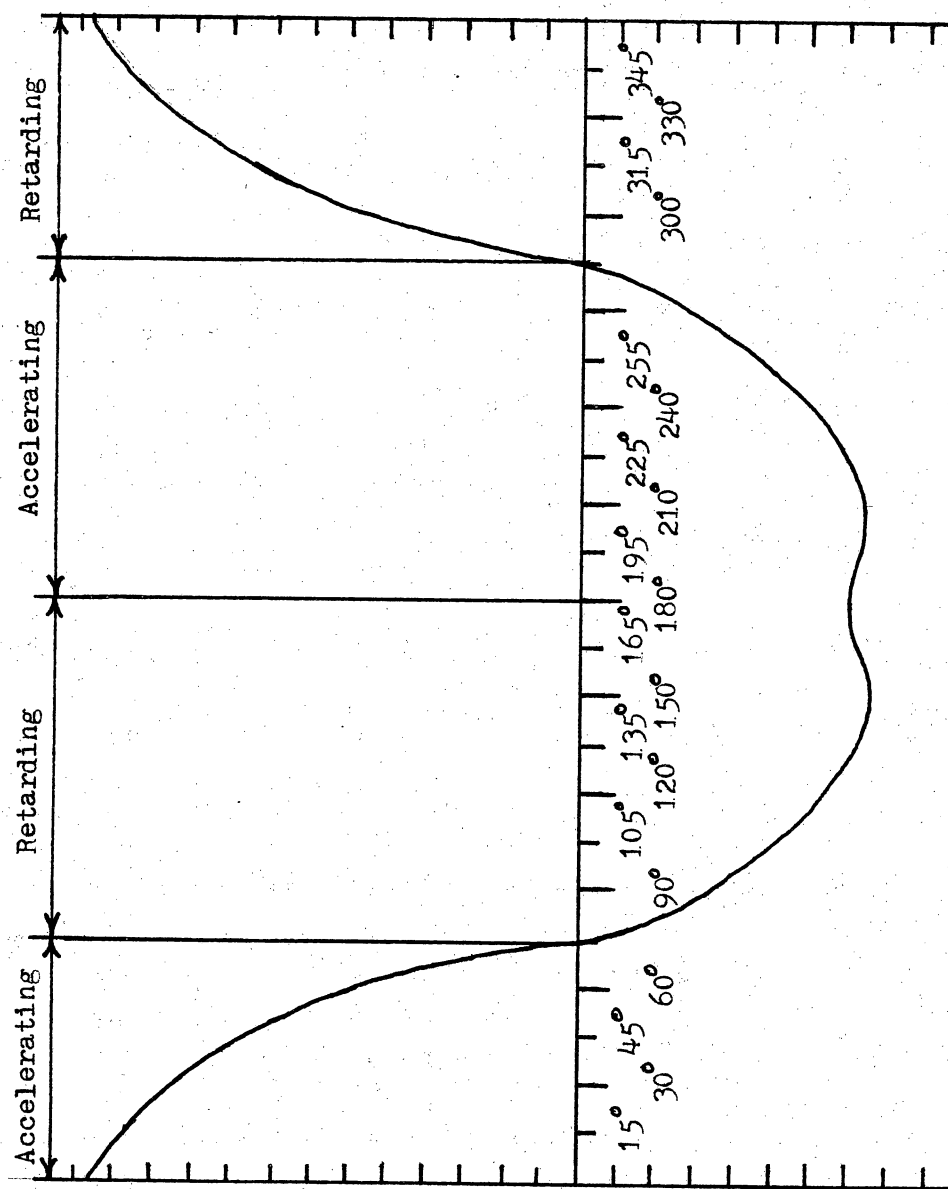
ILL.12 The vertical axis represents the magnitude and direction of the secondary forces, in relation to the crankshaft rotation, which is shown on the horizontal axis.

Since the inertia forces applied to an engine are the sum of the primary and secondary forces, the graphs illustrated by Illustrations 6 and 12 can be added together to give the combined forces on the engine. Illustration 13 represents this combination.

It is important to notice that the magnitude at T.D.C. is greater than at B.D.C. This is a result of the secondary forces being in an upward direction at B.D.C. (180 degrees of crankshaft rotation) and the primary forces being in a downward direction at the same time. They have a tendency to cancel each other.

By returning to the example attached to Illustration 11, it will help to explain the difference in values found at T.D.C. and B.D.C. In this example, it takes 74 degrees of crankshaft rotation to accelerate from T.D.C. to the point of maximum velocity and 106 degrees to decelerate from that point to B.D.C. The piston inertia forces are greater during the 148 degrees to and from T.D.C. What this means from a practical standpoint is, that the force created by a piston traveling to and from T.D.C. cannot be exactly offset (balanced) by the forces of a piston traveling to and from B.D.C. In a vertical twin with a 180 degree crankshaft configuration, the forces of one piston do not balance those of the other piston traveling in the opposite direction.

If shorter connecting rods are employed, the acceleration will take place in a smaller angle of rotation. This results in a bigger difference in the amount of time taken (measured in degrees of crankshaft rotation) to travel to and from B.D.C., as compared to the time



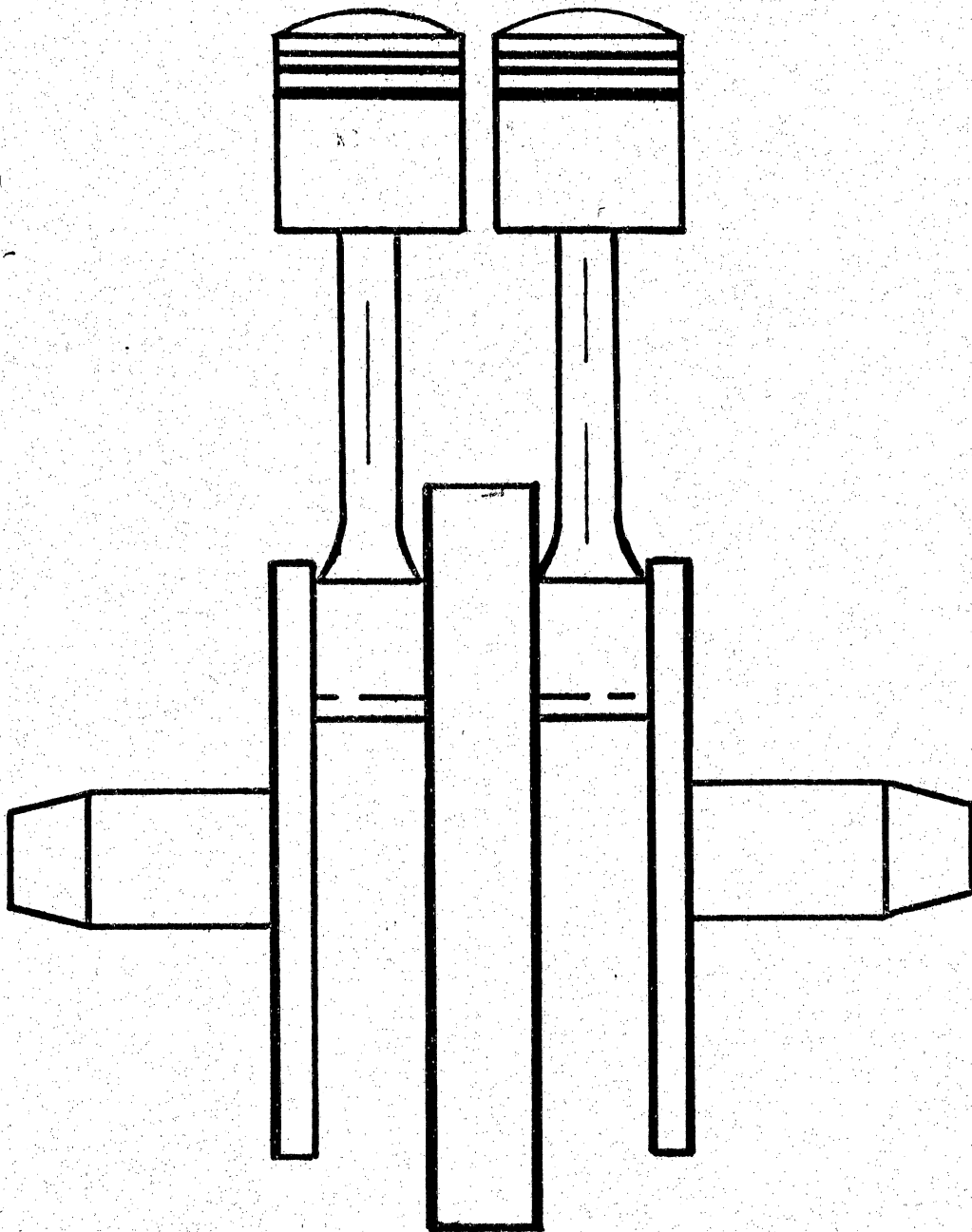
ILL. 13 the magnitude
and direction of
the primary and
secondary forces.

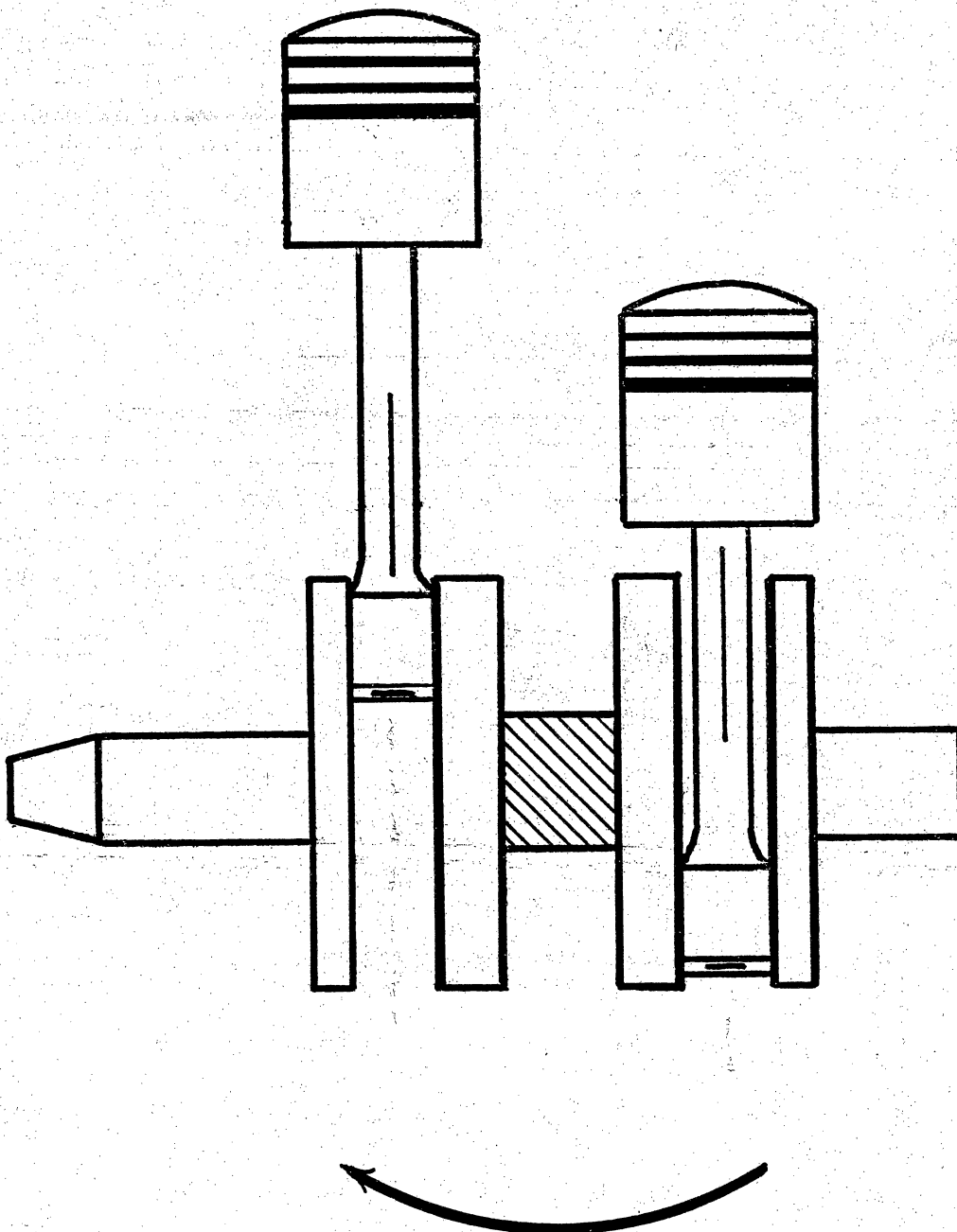
to and from T.D.C. Therefore, the smaller the ratio of rod length to crank throw, the less a piston moving in the opposite direction will balance. That is, a rod length to crank throw ratio of 4:1 will be better balanced as a 180 degree vertical twin than a similar engine with a 3.5:1 ratio.

An engine designer will consider many alternatives when trying to increase the RPM of a particular engine design. One primary consideration must be the force of the piston motion. This is calculated by the formula discussed earlier on page 22. If any component in the formula is reduced, then the loading force will be reduced. Since we intend to increase RPM, we must decrease the weight of the piston or the length of the stroke. The weight of the piston can be reduced only to the point where it can still transfer heat from the crown to the skirt, and out into the atmosphere through the cylinder walls. The alternative is to reduce the stroke, but keep in mind that the piston diameter must increase to retain the same displacement. The rule of thumb is that if an engine has a bore greater than its stroke (over square), it will be able to operate at higher RPM's than an undersquare engine of the same displacement.

Recalling that multiple cylinder engines will tend to balance one piston against another, there are several factors to consider in order to understand the forces in multi-cylinder engines. The first design to be discussed will be the vertical twin. This design is separated into two classifications, the 360 degree crank, and the 180 degree crank. These designs are shown in Illustrations 14 and 15.

ILL. 14 360 degree configuration of a vertical twin.





ILL. 15 180 degree configuration of a vertical twin. The arrow indicates the direction of the rocking couple at this crankshaft position.

The first discussion will consider the 360 degree crankshaft configuration of the vertical twin, which gets its name from the fact that one piston lags the other by 360 degrees. If one piston is approaching T.D.C. on the compression stroke, the other piston lags by 360 degrees and is approaching T.D.C. on the exhaust stroke. This is the point where valve overlap occurs.

The balancing problems of this configuration are the same as those found in a single cylinder engine, but when compared to a single of the same displacement, the smaller bore and shorter stroke will result in much lower primary inertia forces. The secondary forces will also be reduced accordingly and will become very small.

Taking this into consideration, and realizing that the firing intervals are evenly spaced, the vertical twin design produces a very smooth torque output and can be a very vibration-free design.

Several new facts must be considered when discussing the 180 degree crankshaft configuration. The 180 degree crankshaft means that one piston operation lags the other by 180 degrees. This may be seen in Illustration 14B, where one piston is at T.D.C. and the other is at B.D.C. The most apparent result is that if the power stroke of the second cylinder occurs 180 degrees after the first, there will be a greater time lag between that firing and the time when the first piston fires again. This time will be 540 degrees of crankshaft rotation later. This gives rise to a greater fluctuation in engine output torque than that occurring in the 360 degree vertical twin configuration. The inertia forces of each piston are

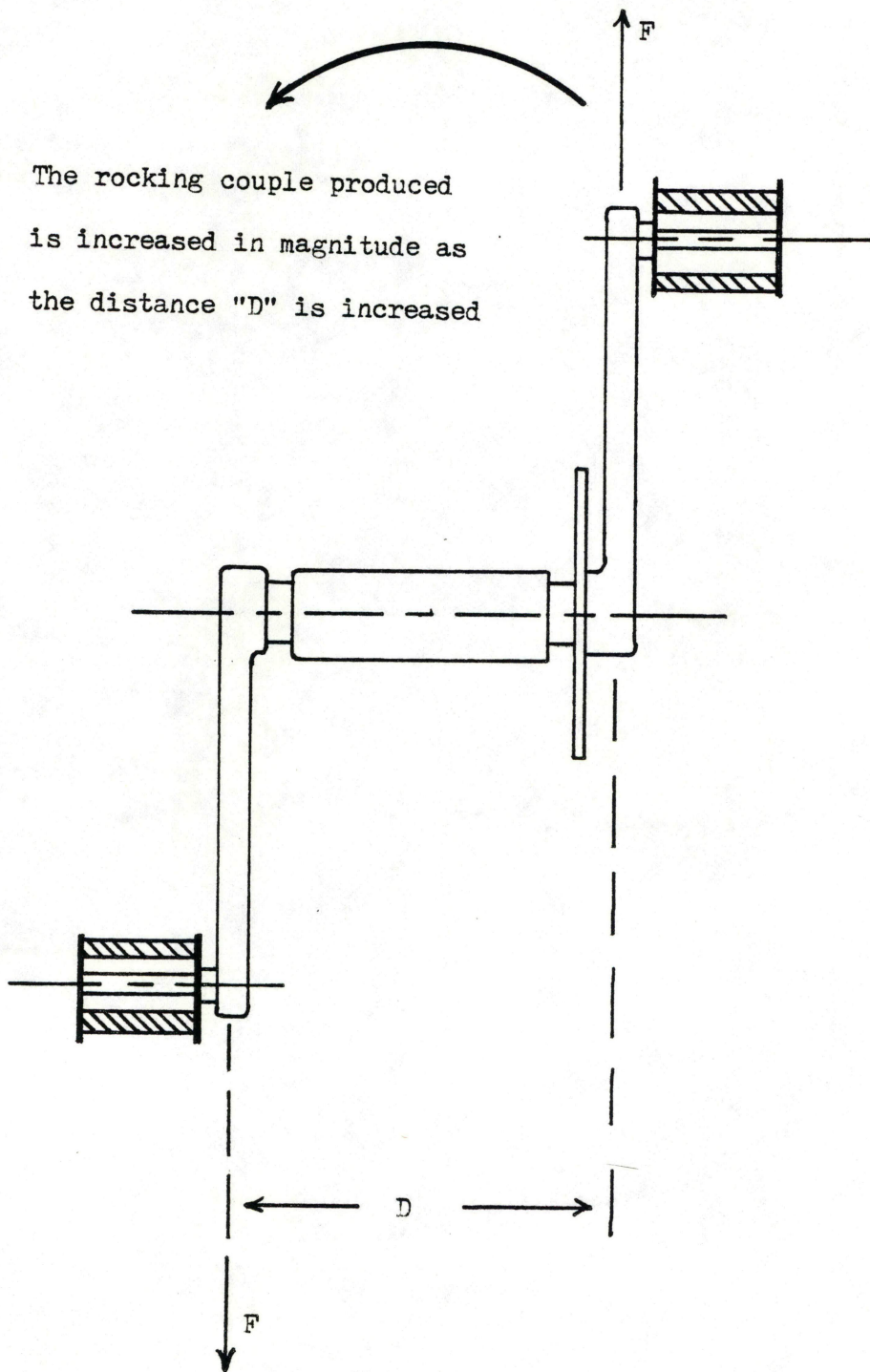
better offset by the piston moving in the opposite direction in this 180 degree crankshaft configuration.

The primary forces of each piston essentially completely cancel each other, and the secondary forces will be identical to those of a single piston as shown in Illustration 13. This may lead to concluding that the 180 degree crankshaft is an extremely smooth and well-balanced engine, but now a new element must be considered. When two offset masses rotate around the same axis in an eccentric fashion, a rocking couple is produced. (See Ill. 15). A rotating couple will also be produced, but because it is easily counterbalanced and is of greatest concern when at T.D.C. and B.D.C., where it adds to the rocking couple, we will deal primarily with the rocking couple.

The effect that is felt from a rocking couple can be illustrated by visualizing the pedals on a bicycle. (See Ill. 16). Consider the centrifugal force of each pedal as a force that tends to pull each pedal in the direction of the arrows (marked "F"). It is also seen that these forces are parallel and in opposite directions. This force will produce a rocking couple in the direction indicated by the curved arrow. As the distance "D" becomes greater, this rocking couple will become stronger. D is representative of the distance between centers of two connecting rods on a 180 degree vertical twin crankshaft assembly. It is also important to notice that the rocking couple is in the opposite direction, 180 degrees of crankshaft rotation later. Because the entire mass of the bicycle pedals is rotating, the rotating couple will be more noticeable than that of an engine that has the rotating couple noticeable at

The force F produces the rocking couple

ILL. 16 The rocking couple produced is increased in magnitude as the distance " D " is increased



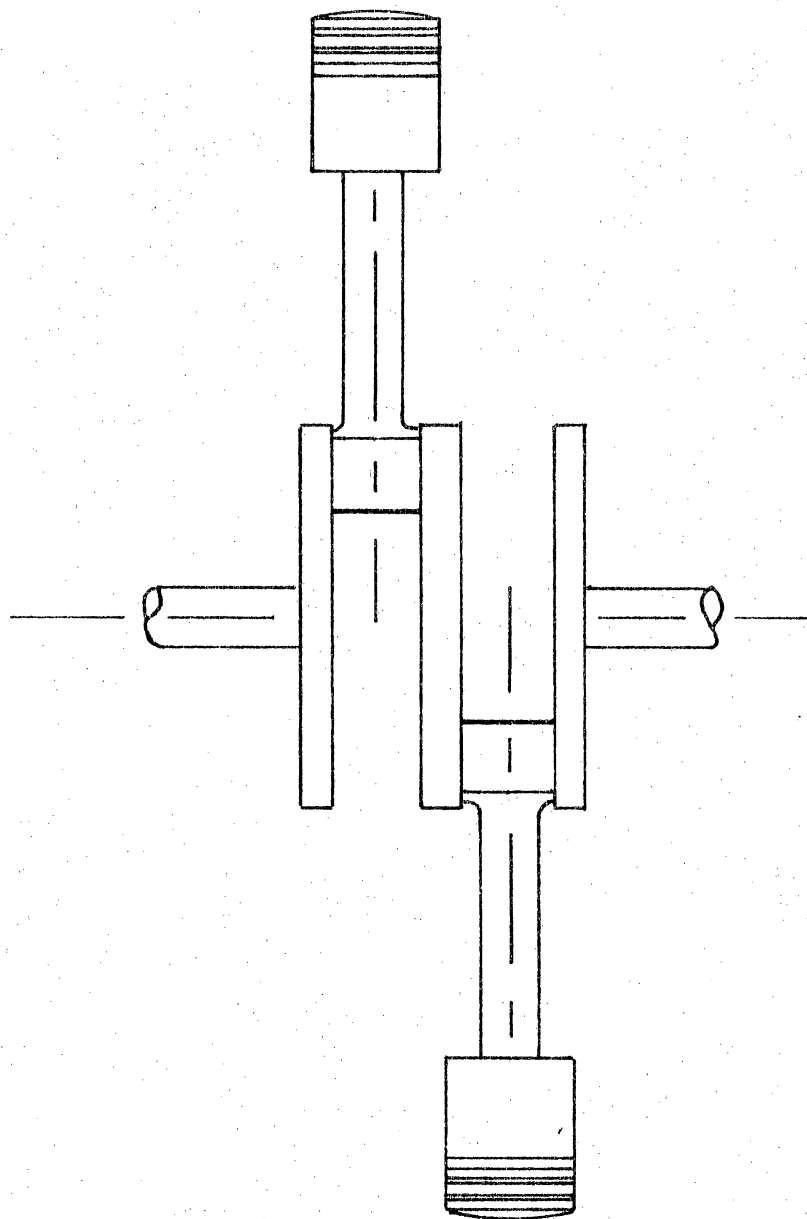
only T.D.C. and B.D.C., which is transmitted as a rocking couple.

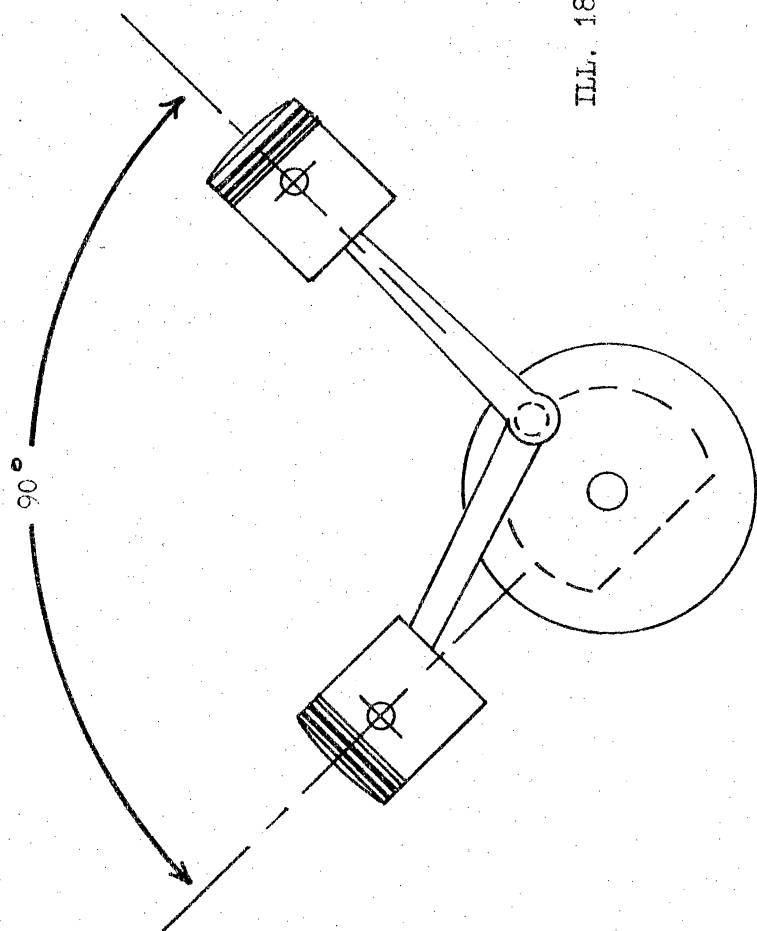
Another 180 degree twin crankshaft configuration is the horizontally opposed flat twin. (See Ill. 17). In this design, the opposite movement of the the piston assemblies completely cancel the primary and secondary forces. There will still be a rocking couple produced, but even this is reduced from a vertical twin 180 degree crankshaft because the distance "D" is reduced as the pistons do not pass each other. The lines of travel of each piston need only be far enough apart to allow for the big end width and the thickness of the web joining the crankpins. .

The last twin to be considered is the "V" twin. In this configuration, the cylinders are not horizontally opposed or vertical, but somewhere in-between. The angle of separation between a horizontally opposed twin would be considered a 180 degree separation, and a vertical twin would have a separation of 0 degrees. The "V" twin will fall at, or sometimes less than, 90 degrees of separation. (See Ill. 18). The cylinders may be mounted in a plane in line with the motorcycle frame as in Harley Davidson or Ducati, or transversely, as in the Honda CX500 and MotoGuzzi.

The typical "V" twin connecting rods will be mounted to a single crankpin and can be side-by-side, which will require that the cylinders be slightly offset by the width of the connecting rod big end or siamesed with one rod forked and straddling the other connecting rod. This side-by-side configuration will produce a slight rocking couple where the more complicated siamese rod will not.

ILL. 17 The horizontal flat twin is relatively vibration free.



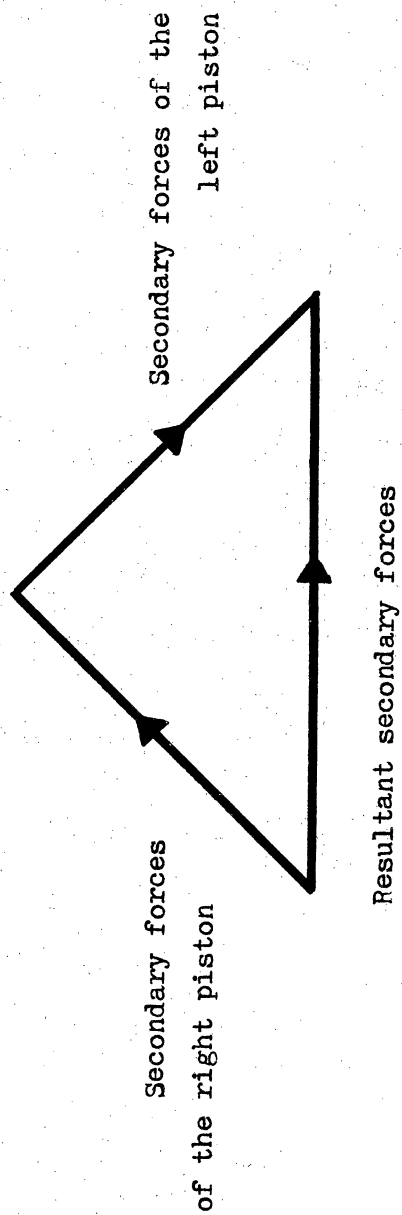


ILL. 18 The 90 degree "V" twin
has advantages in reference
to vibration.

The angle of separation will vary from one design to another, and considerations taken into account by the designers are important to understand. To help in this understanding, consider the single cylinder engine with a 100% balance factor. Recall that with this balance percentage, the inertia forces will be completely counter-balanced by the centrifugal forces when the piston is at T.D.C. and B.D.C. on the vertical plane. However, the inertia forces will be completely out of balance in the horizontal plane, when the piston is at midstroke. If we were to mount a second cylinder and piston assembly on the same crankpin that was just reaching T.D.C., as this second piston reaches midstroke, and at a 90 degree angle from the first piston (the angle of separation between the vertical and horizontal plane), this out of balance centrifugal force would be completely absorbed by the inertia forces of the second piston assembly. This would be a 90 degree "V" twin and the primary forces of each cylinder would be fully balanced. The secondary forces of this design will not be balanced.

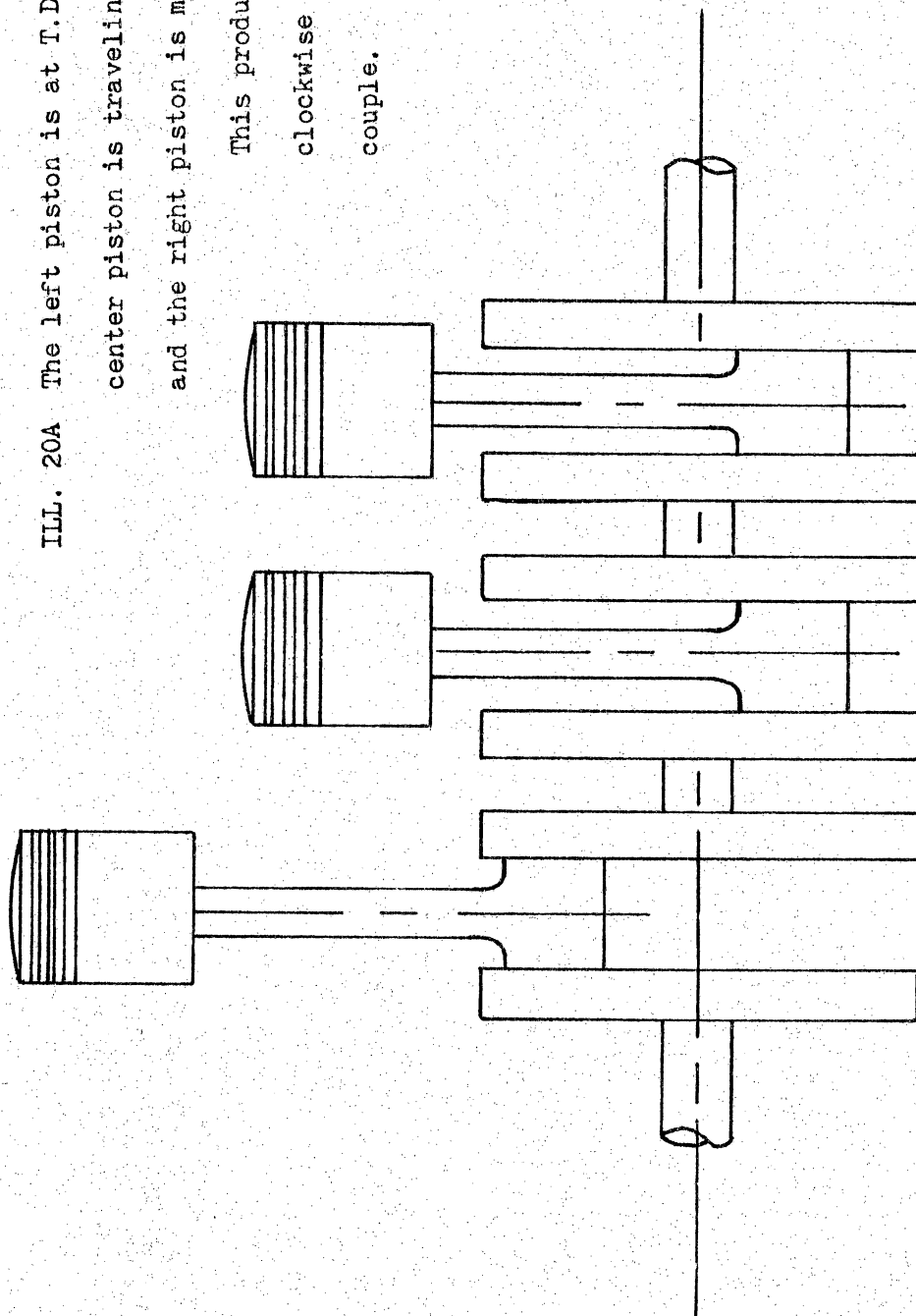
To understand the out of balance secondary forces, consider the situation where the right-hand piston has just reached T.D.C. and the left-hand piston is at midstroke, approaching B.D.C. Illustration 19 graphically represents the resultant secondary force. The vertical components of these forces cancel each other, but the horizontal components add to one another, which gives a resultant force greater than either original force and in a horizontal plane. As can be seen, this force will change its direction each 90 degrees of

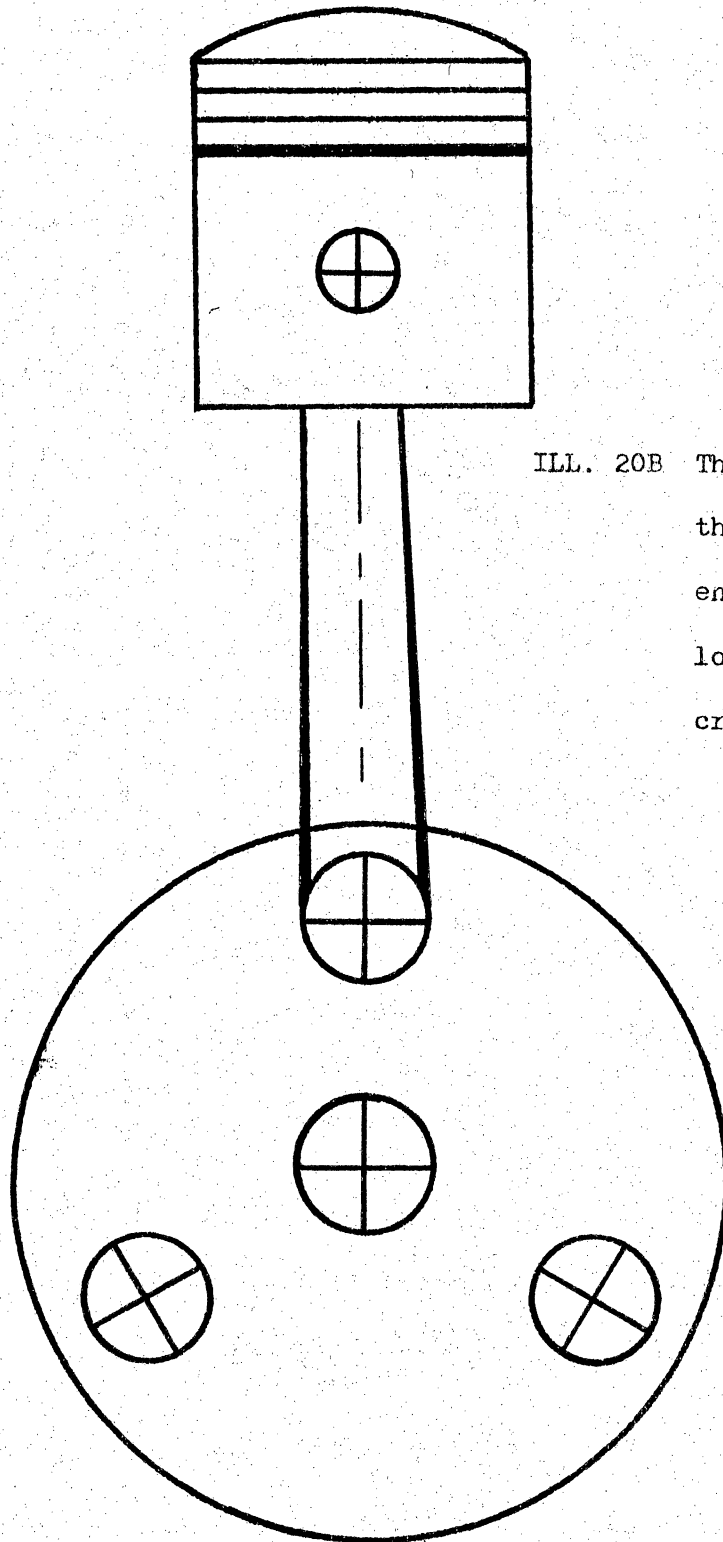
ILL. 19 The secondary forces are added and because they are in different directions, the resultant force is horizontal in either a forward or backward direction.



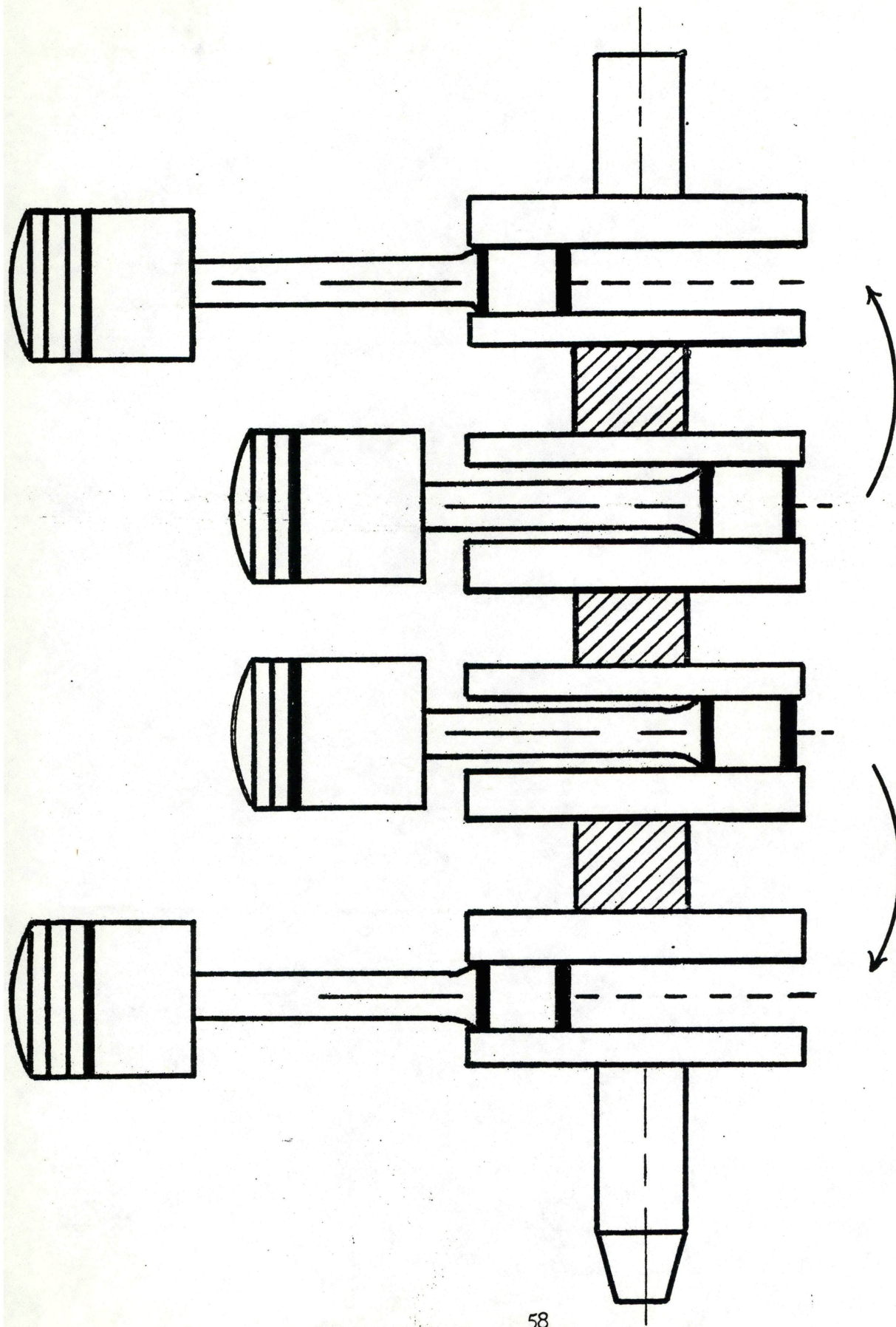
ILL. 20A The left piston is at T.D.C., the
center piston is traveling down
and the right piston is moving up.

This produces a
clockwise rocking
couple.





ILL. 20B The side view of the three cylinder engine shows the location of the crankpins.



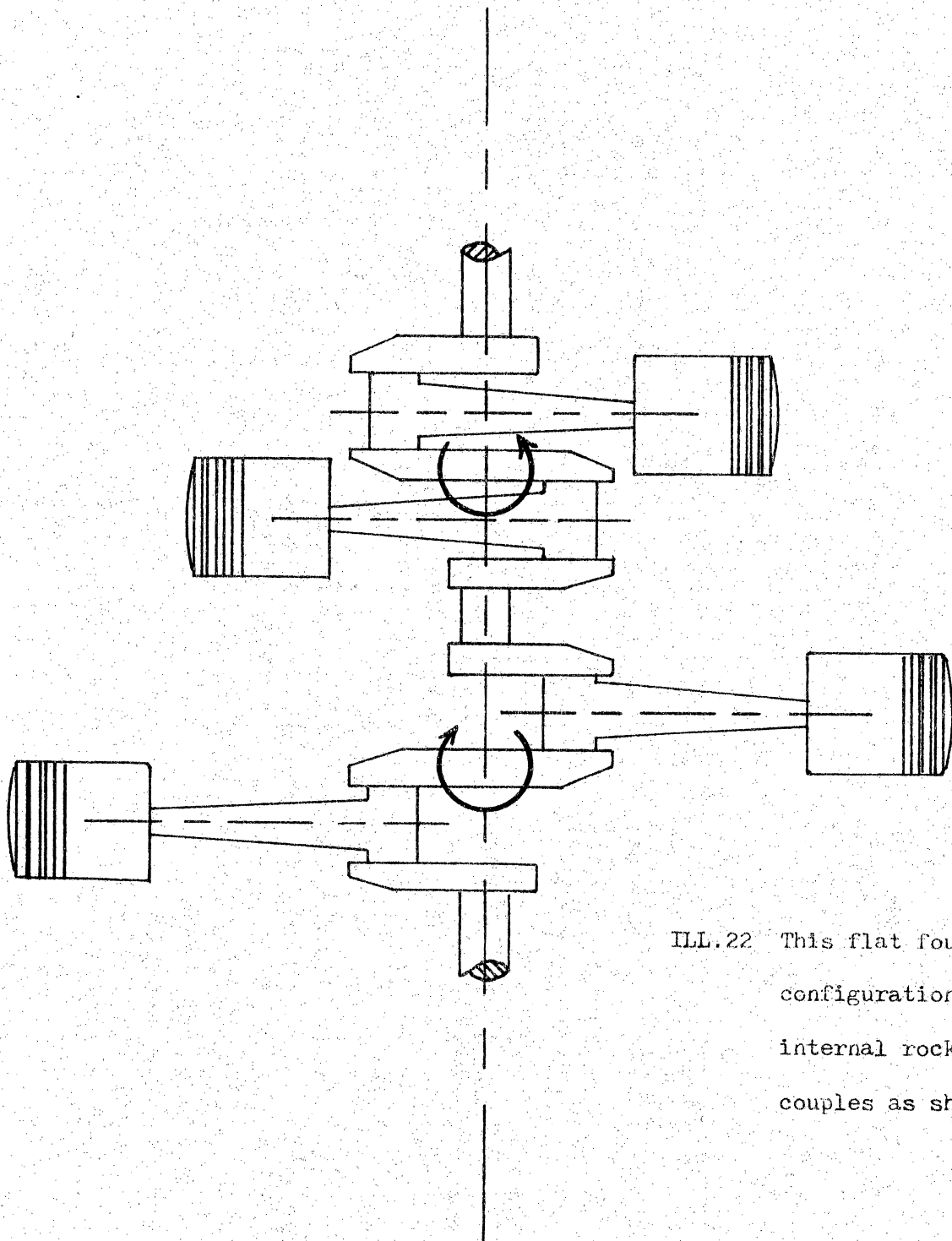
ILL. 21 This shows the rocking couples produced in an in-line four, when in this position.

Consider that each cylinder lags the other by 180 degrees of crankshaft rotation. This divides the four strokes of operation equally, so the 720 degrees required for the complete cycling process will take place in such a manner as to produce a power pulse every 180 degrees of crankshaft rotation.

It might appear that the inertia forces of a piston moving to and from T.D.C. would be completely balanced by those produced by a piston moving to and from B.D.C., but that they are not balanced. The primary forces will be in balance but the secondary forces will not. This design does have a pronounced secondary vibration.

An advantage of the in-line four is that no rocking couple is felt. This is not to say that rocking couples do not exist. They do exist and are quite strong, but are contained within the crankshaft and cancel each other. A very rigid crankshaft and substantial main bearings are required because these rocking couples work against each other. The rocking couples will be about the boss between cylinders 1 and 2 and between 3 and 4, as seen in Illustration 21. This produces a doubly strong rocking couple at the main bearing between cylinders 2 and 3.

The last design to be discussed is the flat four configuration. (See Ill. 22). In this design, a conventional in-line four cylinder crankshaft can be used, but the distances between the crankshaft bosses does not need to be as large because the adjacent pistons do not pass each other. This reduces the magnitude of the internal



ILL.22 This flat four
configuration has
internal rocking
couples as shown.

rocking couple and therefore requires a shorter crankshaft length than occurs in the in-line four. The firing intervals are evenly spaced at 180 degrees.

The counterbalancer which has been mentioned earlier and is shown in Illustration 2 is of great practical importance and is becoming very popular. This balancer is properly called the Lanchester Harmonic Balancer, named after its inventor. Extremely smooth operation can be expected through the use of counterbalancers because they will counter-act all forces resultant from the inertial and centrifugal loading of the crankshaft. Simply stated, the counterbalancers are so timed as to produce forces of opposite magnitude and direction as those created in the crankshaft assembly.

IX. Assignment Sheets

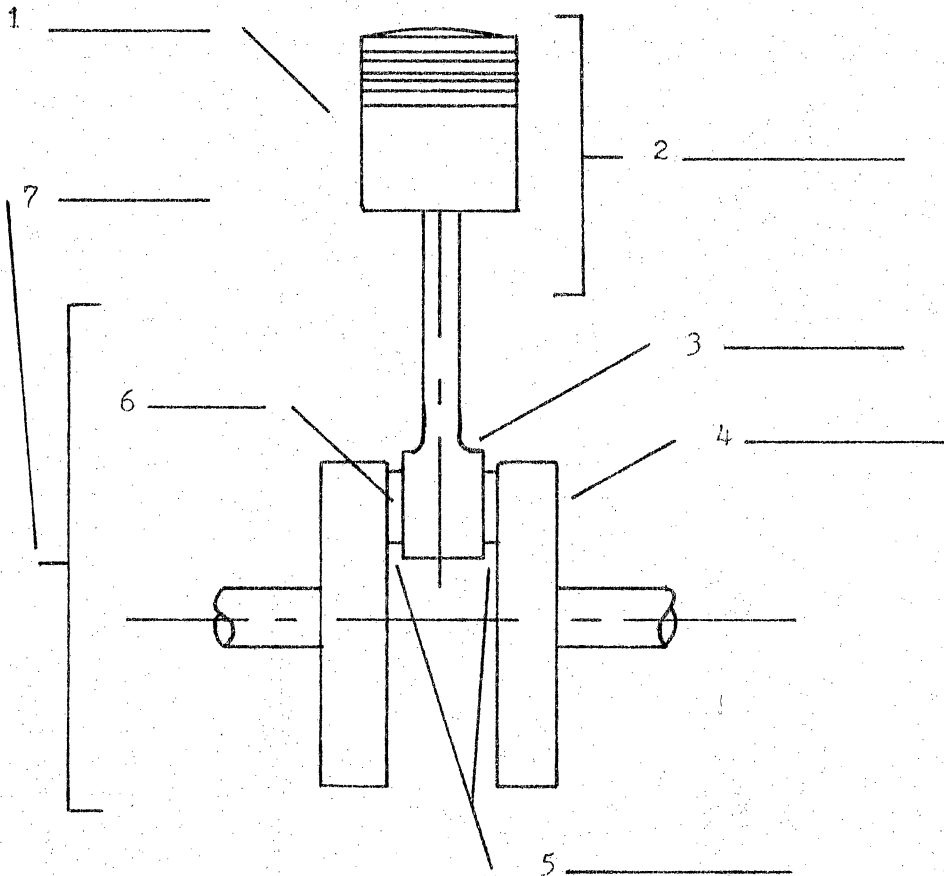
1. Identify Crankshaft Parts.
2. Match Terms and Definitions.
3. Problem Solving.
4. Couple and Configuration Identification.

ENGINE BALANCING

ASSIGNMENT SHEET #2

IDENTIFY CRANKSHAFT PARTS

From the illustration, identify each part of this crankshaft assembly.



ENGINE BALANCING

ASSIGNMENT SHEET # 2

MATCH TERMS AND DEFINITIONS

Match the terms on the right to the correct definitions, by placing the correct number in the blanks on the left. Numbers may be used once, more than once, or not at all.

DEFINITIONS

- _____ A. The force that tries to keep a piston moving upward when it reaches T.D.C.
- _____ B. The strength of a force.
- _____ C. In motion.
- _____ D. The force that causes a pitching about the center in a plane perpendicular to the direction of rotation.
- _____ E. A force that produces rotation.
- _____ F. A vertical twin cylinder engine with one piston approaching T.D.C. when the other approaches B.D.C.
- _____ G. An angle representing one half of the included angle of a crankshaft assembly when a piston reaches its maximum velocity.
- _____ H. A term applied to an engine with a larger bore than stroke.

TERMS

- 1. Dynamic
- 2. Inertia
- 3. Magnitude
- 4. Oversquare
- 5. Rocking Couple
- 6. Theta
- 7. Torque
- 8. Undersquare
- 9. 180 degree twin
- 10. 360 degree twin

ENGINE BALANCING

ASSIGNMENT SHEET #3

PROBLEMS RELATING TO ENGINE BALANCE

Given the appropriate information, solve for the specified unknown. Show your computations on a separate sheet of paper.

1. If a piston assembly weighs 12 oz., and the stroke of this single cylinder four cycle engine is 1.992 inches with a bore of 2.776 inches, what will be the inertia forces at 3000 RPM and at 6000 RPM? _____
2. If a piston weighs 11 oz., the wrist pin and circlips weigh 1.5 oz., the upper half of the connecting rod weighs 1.5 oz., and the rings weigh 1 oz., with a bore of 2.44 inches and a stroke of 2.56 inches, what will be the inertia forces at 7000 RPM? _____
3. With the following information, calculate at what position (before or after T.D.C.), the piston assembly reaches maximum velocity. The rod length is 4.1 inches and the stroke is 2.2 inches. _____
4. If the piston assembly in problem #3 weighed 13 oz., calculate the secondary forces at 5000 RPM. _____

5. If the secondary forces of the pistons in a 90° "V" twin were 210 pounds each, what is the magnitude of the resultant secondary force? _____

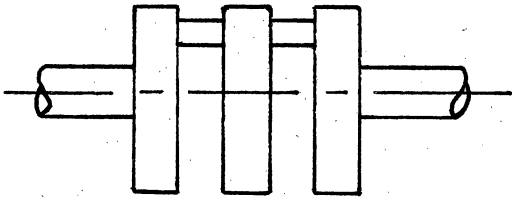
ENGINE BALANCING

ASSIGNMENT SHEET #4

ROCKING COUPLE AND CONFIGURATION IDENTIFICATION

In the following illustrations, identify the crankshaft configurations and the direction of all rocking couples.

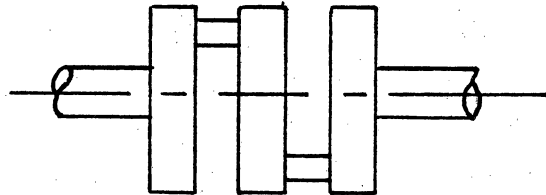
1)



Configuration _____

Rocking Couple _____

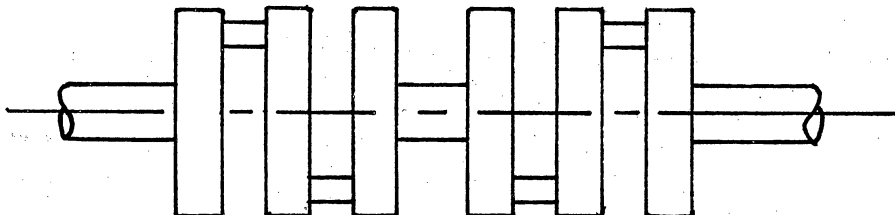
2)



Configuration _____

Rocking Couple _____

3)



Configuration _____

Rocking Couple _____

ENGINE BALANCING

ANSWERS TO ASSIGNMENT SHEETS

Answers to Assignment Sheet #1

1. Piston
2. Piston assembly (less rings) = reciprocating mass
3. Connecting rod big end
4. Crankshaft flywheel half
5. Connecting rod axial clearance
6. Crankshaft journal
7. Rotating mass

Answers to Assignment Sheet #2

- A. 2
- B. 3
- C. 1
- D. 5
- E. 7
- F. 9
- G. 6
- H. 4

Answers to Assignment Sheet #3

1. Given:

Piston assembly weight = 12 oz. = 12/16 lb. = .75 lb.

Stroke = 1.992 inches

Bore = 2.776 inches

RPM = 3000 RPM

RPM = 6000 RPM

Find:

Inertia forces at 3000 RPM

Inertia forces at 6000 RPM

Formula:

$$\begin{aligned} IF &= (.0000142)(W)(\text{RPM}^2)(S) \\ &= (.0000142)(.75 \text{ lb.})(3000^2)(1.992 \text{ in.}) \\ &= 189.9 \text{ lb. @ 3000 RPM} \end{aligned}$$

$$\begin{aligned} IF &= (.0000142)(W)(\text{RPM}^2)(S) \\ &= (.0000142)(.75 \text{ lb.})(6000^2)(1.992 \text{ in.}) \\ &= 763.7 \text{ lb. @ 6000 RPM} \end{aligned}$$

Answers to Assignment Sheet #3 (Continued)

2. Given:

Piston assembly weight	= 11 oz.
Wristpin and circlip weight	= 1.5 oz.
Connecting rod (reciprocating) weight	= 1.5 oz.
Ring weight	= 1 oz.
Bore	= 2.44 inches
Stroke	= 2.56 inches
RPM	= 7000 RPM

Find:

Inertia force at 7000 RPM

Formula:

$$\begin{aligned} IF &= (.0000142)(W)(\text{RPM}^2)(S) \\ &= (.0000142)(.875 \text{ lb.})(7000^2)(2.56 \text{ in.}) \\ &= 1558.59 \text{ lb. @ 7000 RPM} \end{aligned}$$

Answers to Assignment Sheet #3 (Continued)

3. Given:

Rod Length = 4.1 inches

Stroke = 2.2 inches

Find:

Point of maximum piston velocity

Formula:

$$\text{COT Angle} = \frac{\text{Radius of Crank Throw}}{\text{Rod Length}}$$

$$= \frac{1.1 \text{ inches}}{4.1 \text{ inches}}$$

$$\text{COT} = .2683$$

$$\text{Angle} = 75 \text{ (approximately)}$$

Therefore:

The maximum piston velocity will be achieved at approximately

75° B.T.D.C. and 75° A.T.D.C.

Answers to Assignment Sheet #3 (Continued)

4. Given:

Rod Length = 4.1 inches

Stroke = 2.2 inches

RPM = 5000 RPM

Piston assembly weight = 13 oz. = $13/16$ lb. = .8125

Find:

Secondary Forces

Formula:

$$\begin{aligned}\text{Secondary Forces} &= \left(\frac{\text{Radius of Crank Throw}}{\text{Rod Length}} \right) (\text{Primary Forces}) \\ &= \left(\frac{1.1 \text{ inches}}{4.1 \text{ inches}} \right) (\text{P.F.})\end{aligned}$$

$$\begin{aligned}\text{Primary Forces} &= (.0000142)(w)(\text{RPM}^2)(S) \\ &= (.0000142)(.8125 \text{ lb.})(5000^2)(2.2 \text{ in.}) \\ &= 634.56 \text{ lb. @ 5000 RPM}\end{aligned}$$

$$\begin{aligned}\text{Secondary Forces} &= (.2683)(634.56 \text{ lb.}) \\ &= 170.25 \text{ lb.}\end{aligned}$$

Answers to Assignment Sheet #3 (Continued)

5. Given:

Secondary Forces = 210 lb.

Find:

Resultant secondary forces

Formula:

$$\begin{aligned} M &= (S_R)^2 + (S_L)^2 \\ &= (210)^2 + (210)^2 \\ &= 44100 \text{ lb.}^2 + 44100 \text{ lb.}^2 \\ &= 88200 \text{ lb.}^2 \\ &= 296.98 \text{ lb.} \end{aligned}$$

Answers to Assignment Sheet #4

1. Configuration ----- 360 degree twin

Rocking Couple ----- none

2. Configuration ----- 180 degree twin

Rocking Couple ----- In a clockwise rotation

3. Configuration ----- In-line four cylinder

Rocking Couples -----

Between #1 and #2 -- clockwise

Between #3 and #4 -- counter clockwise

X. Job Sheets

1. Measurement Exercise
2. Crankshaft Rebuild

ENGINE BALANCING

JOB SHEET #1

MEASUREMENT EXERCISE

Select an engine and measure its stroke, the connecting rod length, radial and axial clearances, crankshaft width, and weigh the piston assembly.

Stroke Measurement

Connecting Rod Length

Weight of Piston

Weight of Wristpin and Circlips

Weight of Reciprocating Part of Connecting Rod

Weight of Piston Assembly

TOTAL

	OPTIMUM	SERVICE LIMIT	ACTURAL MEASUREMENT
Radial Clearance	_____	_____	_____
Axial Clearance	_____	_____	_____
Crankshaft Width	_____	_____	_____

Student Name

Instructor Verification

Date

ENGINE BALANCING

JOB SHEET #2

Disassemble, inspect, reassemble, and true a single cylinder crankshaft assembly.

PROCEDURE:

1. Select a single cylinder crankshaft assembly.
2. Measure the crankshaft width, radial clearance and axial clearance.
3. Visually inspect for any damage.
4. Visually inspect for any assembly oddities. (e.g. oil passages, journal offset, etc.)
5. Remove any main bearings.
6. Select appropriate press plate and press pin.
7. Carefully set up and press one flywheel off of the assembly.
8. Remove connecting rod, bearings, and thrust washers.
9. Inspect crankshaft journal, particularly for positioning of oil passages.
10. Change press plate for a simple heavy duty plate that will accept crankshaft journal.
11. Press crankshaft journal from second flywheel half.
12. Clean flywheel halves and coat new journal with an anti-seize compound.
13. Press new journal into one flywheel half; stop just short of flush with outer surface.
14. Lubricate and assemble thrust washers, connecting rod, and bearing on this flywheel half.

15. Place second half of crankshaft on press with assembly placed squarely on top and press together, insuring that axial clearance, flywheel width, and centering are all correct.
16. Check assembly for trueness on truing stand and adjust to optimum specifications given in the appropriate service manual.

ENGINE BALANCING

COMPETENCY CHECK LIST

MEASUREMENT:	Date	Instructor Initials
Use of feeler gauges	_____	_____
Use of vernier caliper	_____	_____
Use of dial indicator	_____	_____
TOOLS:		
Press and press plates	_____	_____
Crankshaft truing stand	_____	_____
Scale or balance	_____	_____
PROCEDURES:		
Crankshaft rebuilding	_____	_____
Crankshaft truing	_____	_____

Student Name _____

Date _____

Name _____

ENGINE BALANCING

EVALUATION INSTRUMENT

Read the following questions and circle the letter of the correct answer. In all questions there will be only one correct answer. Each question is worth 5 points.

1. The two reactions that are felt external to the engine are output torque and the unwelcome vibration produced by inertia loading of the piston assembly.

A. TRUE

B. FALSE
2. The formula for calculating inertia forces resultant from the split second deceleration of a piston assembly at T. D.C. is:
$$I.F. = (.0000142)(W)(RPM^2)(S).$$

A. TRUE

B. FALSE
3. When inertia forces are at their maximum, piston velocity will be zero, and when piston velocity is greatest, the inertia forces are zero.

A. TRUE

B. FALSE

4. The inertia forces cause the connecting rod to be under tension at B.D.C. and compression at T.D.C.
- A. TRUE
- B. FALSE
5. When an engine is said to be in 100% balance, this refers to a vertical balance and is true only at a specific RPM.
- A. TRUE
- B. FALSE
6. The 100% balance referred to in the previous problem is not desirable because it will be 100% out of balance in the horizontal plane.
- A. TRUE
- B. FALSE
7. Since the formula for finding secondary forces is:
- $$\text{S.F.} = \left(\frac{R}{\text{rod length}} \right) (\text{P.F.}),$$
- and RPM is not included in this formula, the secondary forces of an engine are not dependent on RPM.
- A. TRUE
- B. FALSE
8. In a 180° twin, a larger rod length to crank throw ratio will produce a better natural engine balance.
- A. TRUE
- B. FALSE

9. An engine that is considered to be undersquare will typically be able to operate at a higher RPM than an oversquare engine of the same displacement.
- A. TRUE
 - B. FALSE
10. The 360 degree twin produces a greater rocking couple than the 180 degree twin.
- A. TRUE
 - B. FALSE
11. A rocking couple is felt only when a piston is at T.D.C. and B.D.C.
- A. TRUE
 - B. FALSE
12. The magnitude of the resultant secondary forces in a 90 degree "V" twin will be greater than the secondary forces of either the right or left cylinder.
- A. TRUE
 - B. FALSE
13. The rocking couple produced by an in-line triple is difficult to counterbalance with an externally driven balancer shaft.
- A. TRUE
 - B. FALSE
14. The in-line four cylinder has a pronounced internal rocking couple, so it requires very strong main bearings and a rigid crankshaft.
- A. TRUE
 - B. FALSE

15. The internal rocking couple of the flat four engine configuration is greater than that of the vertical in-line four.
- A. TRUE
 - B. FALSE
16. The firing intervals of the conventional in-line and flat-four designs, both produce even firing intervals of 180 degrees.
- A. TRUE
 - B. FALSE
17. The Lanchester Harmonic Balancer is external to the crankshaft and is capable of completely counteracting both the inertia loading and the loading resultant from centrifugal forces.
- A. TRUE
 - B. FALSE
18. Which item(s) listed below are NOT considered part of the reciprocating mass in an internal combustion engine?
- A. Piston
 - B. Rings
 - C. Wristpin and Circlips
 - D. Upper part of the Connecting Rod
19. Maximum piston velocity is reached at:
- A. T.D.C.
 - B. Nearly midstroke
 - C. Midstroke exactly
 - D. B.D.C.

20. The included angle of an engine is:

- A. That angle created by a line from the center of a crankshaft to the center of the crank pin, when the crankshaft is positioned at a point where the piston is at maximum velocity, and the line of stroke of that engine.
- b. The angle created by a line from the center of the crank pin to the center of rotation, when the piston reaches maximum velocity on the upward stroke, and that same line when the piston is on the downward stroke.
- C. 180 degrees
- D. The angle between the cylinders of a "V" twin engine.

ENGINE BALANCING

ANSWERS TO TEST

1. A. True
2. A. True
3. A. True
4. B. False
5. A. True
6. A. True
7. B. False
8. A. True
9. B. False
10. B. False
11. A. True
12. A. True
13. F. False
14. A. True
15. A. False
16. A. True
17. A. True
18. B. Rings
19. P. Nearly midstroke
20. B. The angle created by a line from the center of the crank pin to the center of rotation, when the piston reaches maximum velocity on the upward stroke, and that same line when the piston is on the downward stroke.

APPENDIX A

TRIG TABLES

natural trigonometric functions

Degrees	Sin	Cos	Tan	Cot	Sec	Csc	
0° 00'	.0000	1.0000	.0000		1.000		90° 00'
10	.0029	1.0000	.0029	343.8	1.000	343.8	50
20	.0058	1.0000	.0058	171.9	1.000	171.9	40
30	.0087	1.0000	.0087	114.6	1.000	114.6	30
40	.0116	.9999	.0116	85.94	1.000	85.95	20
50	.0145	.9999	.0145	68.75	1.000	68.76	10
1° 00'	.0175	.9998	.0175	57.29	1.000	57.30	89° 00'
10	.0204	.9998	.0204	49.10	1.000	49.11	50
20	.0233	.9997	.0233	42.96	1.000	42.98	40
30	.0262	.9997	.0262	38.19	1.000	38.20	30
40	.0291	.9996	.0291	34.37	1.000	34.38	20
50	.0320	.9995	.0320	31.24	1.001	31.26	10
2° 00'	.0349	.9994	.0349	28.64	1.001	28.65	88° 00'
10	.0378	.9993	.0378	26.43	1.001	26.45	50
20	.0407	.9992	.0407	24.54	1.001	24.56	40
30	.0436	.9990	.0437	22.90	1.001	22.93	30
40	.0465	.9989	.0466	21.47	1.001	21.49	20
50	.0494	.9988	.0495	20.21	1.001	20.23	10
3° 00'	.0523	.9986	.0524	19.08	1.001	19.11	87° 00'
10	.0552	.9985	.0553	18.07	1.002	18.10	50
20	.0581	.9983	.0582	17.17	1.002	17.20	40
30	.0610	.9981	.0612	16.35	1.002	16.38	30
40	.0640	.9980	.0641	15.60	1.002	15.64	20
50	.0669	.9978	.0670	14.92	1.002	14.96	10
4° 00'	.0698	.9976	.0699	14.30	1.002	14.34	86° 00'
10	.0727	.9974	.0729	13.73	1.003	13.76	50
20	.0756	.9971	.0758	13.20	1.003	13.23	40
30	.0785	.9969	.0787	12.71	1.003	12.75	30
40	.0814	.9967	.0816	12.25	1.003	12.29	20
50	.0843	.9964	.0846	11.83	1.004	11.87	10
5° 00'	.0872	.9962	.0875	11.43	1.004	11.47	85° 00'
10	.0901	.9959	.0904	11.06	1.004	11.10	50
20	.0929	.9957	.0934	10.71	1.004	10.76	40
30	.0958	.9954	.0963	10.39	1.005	10.43	30
40	.0987	.9951	.0992	10.08	1.005	10.13	20
50	.1016	.9948	.1022	9.788	1.005	9.839	10
6° 00'	.1045	.9945	.1051	9.514	1.006	9.567	84° 00'
10	.1074	.9942	.1080	9.255	1.006	9.309	50
20	.1103	.9939	.1110	9.010	1.006	9.065	40
30	.1132	.9936	.1139	8.777	1.006	8.834	30
40	.1161	.9932	.1169	8.556	1.007	8.614	20
50	.1190	.9929	.1198	8.345	1.007	8.405	10
7° 00'	.1219	.9925	.1228	8.144	1.008	8.206	83° 00'
10	.1248	.9922	.1257	7.953	1.008	8.016	50
20	.1276	.9918	.1287	7.770	1.008	7.834	40
30	.1305	.9914	.1317	7.596	1.009	7.661	30
40	.1334	.9911	.1346	7.429	1.009	7.496	20
50	.1363	.9907	.1376	7.269	1.009	7.337	10
8° 00'	.1392	.9903	.1405	7.115	1.010	7.185	82° 00'
10	.1421	.9899	.1435	6.968	1.010	7.040	50
20	.1449	.9894	.1465	6.827	1.011	6.900	40
30	.1478	.9890	.1495	6.691	1.011	6.765	30
40	.1507	.9886	.1524	6.561	1.012	6.636	20
50	.1536	.9881	.1554	6.435	1.012	6.512	10
9° 00'	.1564	.9877	.1584	6.314	1.012	6.392	81° 00'
	Cos	Sin	Cot	Tan	Csc	Sec	Degrees

natural trigonometric functions (continued)

Degrees	Sin	Cos	Tan	Cot	Sec	Csc	
9° 00'	.1564	.9877	.1584	6.314	1.012	6.392	81° 00'
10	.1593	.9872	.1614	6.197	1.013	6.277	50
20	.1622	.9868	.1644	6.084	1.013	6.166	40
30	.1650	.9863	.1673	5.976	1.014	6.059	30
40	.1679	.9858	.1703	5.871	1.014	5.955	20
50	.1708	.9853	.1733	5.769	1.015	5.855	10
10° 00'	.1736	.9848	.1763	5.671	1.015	5.759	80° 00'
10	.1765	.9843	.1793	5.576	1.016	5.665	50
20	.1794	.9838	.1823	5.485	1.016	5.575	40
30	.1822	.9833	.1853	5.396	1.017	5.487	30
40	.1851	.9827	.1883	5.309	1.018	5.403	20
50	.1880	.9822	.1914	5.226	1.018	5.320	10
11° 00'	.1908	.9816	.1944	5.145	1.019	5.241	79° 00'
10	.1937	.9811	.1974	5.066	1.019	5.164	50
20	.1965	.9805	.2004	4.989	1.020	5.089	40
30	.1994	.9799	.2035	4.915	1.020	5.016	30
40	.2022	.9793	.2065	4.843	1.021	4.945	20
50	.2051	.9787	.2095	4.773	1.022	4.876	10
12° 00'	.2079	.9781	.2126	4.705	1.022	4.810	78° 00'
10	.2108	.9775	.2156	4.638	1.023	4.745	50
20	.2136	.9769	.2186	4.574	1.024	4.682	40
30	.2164	.9763	.2217	4.511	1.024	4.620	30
40	.2193	.9757	.2247	4.449	1.025	4.560	20
50	.2221	.9750	.2278	4.390	1.026	4.502	10
13° 00'	.2250	.9744	.2309	4.331	1.026	4.445	77° 00'
10	.2278	.9737	.2339	4.275	1.027	4.390	50
20	.2306	.9730	.2370	4.219	1.028	4.336	40
30	.2334	.9724	.2401	4.165	1.028	4.284	30
40	.2363	.9717	.2432	4.113	1.029	4.232	20
50	.2391	.9710	.2462	4.061	1.030	4.182	10
14° 00'	.2419	.9703	.2493	4.011	1.031	4.134	76° 00'
10	.2447	.9696	.2524	3.962	1.031	4.086	50
20	.2476	.9689	.2555	3.914	1.032	4.039	40
30	.2504	.9681	.2586	3.867	1.033	3.994	30
40	.2532	.9674	.2617	3.821	1.034	3.950	20
50	.2560	.9667	.2648	3.776	1.034	3.906	10
15° 00'	.2588	.9659	.2679	3.732	1.035	3.864	75° 00'
10	.2616	.9652	.2711	3.689	1.036	3.822	50
20	.2644	.9644	.2742	3.647	1.037	3.782	40
30	.2672	.9636	.2773	3.606	1.038	3.742	30
40	.2700	.9628	.2805	3.566	1.039	3.703	20
50	.2728	.9621	.2836	3.526	1.039	3.665	10
16° 00'	.2756	.9613	.2867	3.487	1.040	3.628	74° 00'
10	.2784	.9605	.2899	3.450	1.041	3.592	50
20	.2812	.9596	.2931	3.412	1.042	3.556	40
30	.2840	.9588	.2962	3.376	1.043	3.521	30
40	.2868	.9580	.2994	3.340	1.044	3.487	20
50	.2896	.9572	.3026	3.305	1.045	3.453	10
17° 00'	.2924	.9563	.3057	3.271	1.046	3.420	73° 00'
10	.2952	.9555	.3089	3.237	1.047	3.388	50
20	.2979	.9546	.3121	3.204	1.048	3.356	40
30	.3007	.9537	.3153	3.172	1.049	3.326	30
40	.3035	.9528	.3185	3.140	1.049	3.295	20
50	.3062	.9520	.3217	3.108	1.050	3.265	10
18° 00'	.3090	.9511	.3249	3.078	1.051	3.236	72° 00'
	C		Cot	Tan	Csc	Sec	Degrees

natural trigonometric functions (continued)

Degrees	Sin	Cos	Tan	Cot	Sec	Csc	
18° 00'	.3090	.9511	.3249	3.078	1.051	3.236	72° 00'
10	.3118	.9502	.3281	3.047	1.052	3.207	50
20	.3145	.9492	.3314	3.018	1.053	3.179	40
30	.3173	.9483	.3346	2.989	1.054	3.152	30
40	.3201	.9474	.3378	2.960	1.056	3.124	20
50	.3228	.9465	.3411	2.932	1.057	3.098	10
19° 00'	.3256	.9455	.3443	2.904	1.058	3.072	71° 00'
10	.3283	.9446	.3476	2.877	1.059	3.046	50
20	.3311	.9436	.3508	2.850	1.060	3.021	40
30	.3338	.9426	.3541	2.824	1.061	2.996	30
40	.3365	.9417	.3574	2.798	1.062	2.971	20
50	.3393	.9407	.3607	2.773	1.063	2.947	10
20° 00'	.3420	.9397	.3640	2.747	1.064	2.924	70° 00'
10	.3448	.9387	.3673	2.723	1.065	2.901	50
20	.3475	.9377	.3706	2.699	1.066	2.878	40
30	.3502	.9367	.3739	2.675	1.068	2.855	30
40	.3529	.9356	.3772	2.651	1.069	2.833	20
50	.3557	.9346	.3805	2.628	1.070	2.812	10
21° 00'	.3584	.9336	.3839	2.605	1.071	2.790	69° 00'
10	.3611	.9325	.3872	2.583	1.072	2.769	50
20	.3638	.9315	.3906	2.560	1.074	2.749	40
30	.3665	.9304	.3939	2.539	1.075	2.729	30
40	.3692	.9293	.3973	2.517	1.076	2.709	20
50	.3719	.9283	.4006	2.496	1.077	2.689	10
22° 00'	.3746	.9272	.4040	2.475	1.079	2.669	68° 00'
10	.3773	.9261	.4074	2.455	1.080	2.650	50
20	.3800	.9250	.4108	2.434	1.081	2.632	40
30	.3827	.9239	.4142	2.414	1.082	2.613	30
40	.3854	.9228	.4176	2.394	1.084	2.595	20
50	.3881	.9216	.4210	2.375	1.085	2.577	10
23° 00'	.3907	.9205	.4245	2.356	1.086	2.559	67° 00'
10	.3934	.9194	.4279	2.337	1.088	2.542	50
20	.3961	.9182	.4314	2.318	1.089	2.525	40
30	.3987	.9171	.4348	2.300	1.090	2.508	30
40	.4014	.9159	.4383	2.282	1.092	2.491	20
50	.4041	.9147	.4417	2.264	1.093	2.475	10
24° 00'	.4067	.9135	.4452	2.246	1.095	2.459	66° 00'
10	.4094	.9124	.4487	2.229	1.096	2.443	50
20	.4120	.9112	.4522	2.211	1.097	2.427	40
30	.4147	.9100	.4557	2.194	1.099	2.411	30
40	.4173	.9088	.4592	2.177	1.100	2.396	20
50	.4200	.9075	.4628	2.161	1.102	2.381	10
25° 00'	.4226	.9063	.4663	2.145	1.103	2.366	65° 00'
10	.4253	.9051	.4699	2.128	1.105	2.352	50
20	.4279	.9038	.4734	2.112	1.106	2.337	40
30	.4305	.9026	.4770	2.097	1.108	2.323	30
40	.4331	.9013	.4806	2.081	1.109	2.309	20
50	.4358	.9001	.4841	2.066	1.111	2.295	10
26° 00'	.4384	.8988	.4877	2.050	1.113	2.281	64° 00'
10	.4410	.8975	.4913	2.035	1.114	2.268	50
20	.4436	.8962	.4950	2.020	1.116	2.254	40
30	.4462	.8949	.4986	2.006	1.117	2.241	30
40	.4488	.8936	.5022	1.991	1.119	2.228	20
50	.4514	.8923	.5059	1.977	1.121	2.215	10
27° 00'	.4540	.8910	.5095	1.963	1.122	2.203	63° 00'
	Cos	Sin	Cot	Tan	Csc	Sec	Degrees

natural trigonometric functions (continued)

Degrees	Sin	Cos	Tan	Cot	Sec	Csc	
27° 00'	.4540	.8910	.5095	1.963	1.122	2.203	63° 00'
10	.4566	.8897	.5132	1.949	1.124	2.190	50
20	.4592	.8884	.5169	1.935	1.126	2.178	40
30	.4617	.8870	.5206	1.921	1.127	2.166	30
40	.4643	.8857	.5243	1.907	1.129	2.154	20
50	.4669	.8843	.5280	1.894	1.131	2.142	10
28° 00'	.4695	.8829	.5317	1.881	1.133	2.130	62° 00'
10	.4720	.8816	.5354	1.868	1.134	2.118	50
20	.4746	.8802	.5392	1.855	1.136	2.107	40
30	.4772	.8788	.5430	1.842	1.138	2.096	30
40	.4797	.8774	.5467	1.829	1.140	2.085	20
50	.4823	.8760	.5505	1.816	1.142	2.074	10
29° 00'	.4848	.8746	.5543	1.804	1.143	2.063	61° 00'
10	.4874	.8732	.5581	1.792	1.145	2.052	50
20	.4899	.8718	.5619	1.780	1.147	2.041	40
30	.4924	.8704	.5658	1.767	1.149	2.031	30
40	.4950	.8689	.5696	1.756	1.151	2.020	20
50	.4975	.8675	.5735	1.744	1.153	2.010	10
30° 00'	.5000	.8660	.5774	1.732	1.155	2.000	60° 00'
10	.5025	.8646	.5812	1.720	1.157	1.990	50
20	.5050	.8631	.5851	1.709	1.159	1.980	40
30	.5075	.8616	.5890	1.698	1.161	1.970	30
40	.5100	.8601	.5930	1.686	1.163	1.961	20
50	.5125	.8587	.5969	1.675	1.165	1.951	10
31° 00'	.5150	.8572	.6009	1.664	1.167	1.942	59° 00'
10	.5175	.8557	.6048	1.653	1.169	1.932	50
20	.5200	.8542	.6088	1.643	1.171	1.923	40
30	.5225	.8526	.6128	1.632	1.173	1.914	30
40	.5250	.8511	.6168	1.621	1.175	1.905	20
50	.5275	.8496	.6208	1.611	1.177	1.896	10
32° 00'	.5299	.8480	.6249	1.600	1.179	1.887	58° 00'
10	.5324	.8465	.6289	1.590	1.181	1.878	50
20	.5348	.8450	.6330	1.580	1.184	1.870	40
30	.5373	.8434	.6371	1.570	1.186	1.861	30
40	.5398	.8418	.6412	1.560	1.188	1.853	20
50	.5422	.8403	.6453	1.550	1.190	1.844	10
33° 00'	.5446	.8387	.6494	1.540	1.192	1.836	57° 00'
10	.5471	.8371	.6536	1.530	1.195	1.828	50
20	.5495	.8355	.6577	1.520	1.197	1.820	40
30	.5519	.8339	.6619	1.511	1.199	1.812	30
40	.5544	.8323	.6661	1.501	1.202	1.804	20
50	.5568	.8307	.6703	1.492	1.204	1.796	10
34° 00'	.5592	.8290	.6745	1.483	1.206	1.788	56° 00'
10	.5616	.8274	.6787	1.473	1.209	1.781	50
20	.5640	.8258	.6830	1.464	1.211	1.773	40
30	.5664	.8241	.6873	1.455	1.213	1.766	30
40	.5688	.8225	.6916	1.446	1.216	1.758	20
50	.5712	.8208	.6959	1.437	1.218	1.751	10
35° 00'	.5736	.8192	.7002	1.428	1.221	1.743	55° 00'
10	.5760	.8175	.7046	1.419	1.223	1.736	50
20	.5783	.8158	.7089	1.411	1.226	1.729	40
30	.5807	.8141	.7133	1.402	1.228	1.722	30
40	.5831	.8124	.7177	1.393	1.231	1.715	20
50	.5854	.8107	.7221	1.385	1.233	1.708	10
36° 00'	.5878	.8090	.7265	1.376	1.236	1.701	54° 00'
	Cos	Sin	Cot	Tan	Csc	Sec	Degrees

natural trigonometric functions (continued)

Degrees	Sin	Cos	Tan	Cot	Sec	Csc	
36° 00'	.5878	.8090	.7265	1.376	1.236	1.701	54° 00'
10	.5901	.8073	.7310	1.368	1.239	1.695	50
20	.5925	.8056	.7355	1.360	1.241	1.688	40
30	.5948	.8039	.7400	1.351	1.244	1.681	30
40	.5972	.8021	.7445	1.343	1.247	1.675	20
50	.5995	.8004	.7490	1.335	1.249	1.668	10
37° 00'	.6018	.7986	.7536	1.327	1.252	1.662	53° 00'
10	.6041	.7969	.7581	1.319	1.255	1.655	50
20	.6065	.7951	.7627	1.311	1.258	1.649	40
30	.6088	.7934	.7673	1.303	1.260	1.643	30
40	.6111	.7916	.7720	1.295	1.263	1.636	20
50	.6134	.7898	.7766	1.288	1.266	1.630	10
38° 00'	.6157	.7880	.7813	1.280	1.269	1.624	52° 00'
10	.6180	.7862	.7860	1.272	1.272	1.618	50
20	.6202	.7844	.7907	1.265	1.275	1.612	40
30	.6225	.7826	.7954	1.257	1.278	1.606	30
40	.6248	.7808	.8002	1.250	1.281	1.601	20
50	.6271	.7790	.8050	1.242	1.284	1.595	10
39° 00'	.6293	.7771	.8098	1.235	1.287	1.589	51° 00'
10	.6316	.7753	.8146	1.228	1.290	1.583	50
20	.6338	.7735	.8195	1.220	1.293	1.578	40
30	.6361	.7716	.8243	1.213	1.296	1.572	30
40	.6383	.7698	.8292	1.206	1.299	1.567	20
50	.6406	.7679	.8342	1.199	1.302	1.561	10
40° 00'	.6428	.7660	.8391	1.192	1.305	1.556	50° 00'
10	.6450	.7642	.8441	1.185	1.309	1.550	50
20	.6472	.7623	.8491	1.178	1.312	1.545	40
30	.6494	.7604	.8541	1.171	1.315	1.540	30
40	.6517	.7585	.8591	1.164	1.318	1.535	20
50	.6539	.7566	.8642	1.157	1.322	1.529	10
41° 00'	.6561	.7547	.8693	1.150	1.325	1.524	49° 00'
10	.6583	.7528	.8744	1.144	1.328	1.519	50
20	.6604	.7509	.8796	1.137	1.332	1.514	40
30	.6626	.7490	.8847	1.130	1.335	1.509	30
40	.6648	.7470	.8899	1.124	1.339	1.504	20
50	.6670	.7451	.8952	1.117	1.342	1.499	10
42° 00'	.6691	.7431	.9004	1.111	1.346	1.494	48° 00'
10	.6713	.7412	.9057	1.104	1.349	1.490	50
20	.6734	.7392	.9110	1.098	1.353	1.485	40
30	.6756	.7373	.9163	1.091	1.356	1.480	30
40	.6777	.7353	.9217	1.085	1.360	1.476	20
50	.6799	.7333	.9271	1.079	1.364	1.471	10
43° 00'	.6820	.7314	.9325	1.072	1.367	1.466	47° 00'
10	.6841	.7294	.9380	1.066	1.371	1.462	50
20	.6862	.7274	.9435	1.060	1.375	1.457	40
30	.6884	.7254	.9490	1.054	1.379	1.453	30
40	.6905	.7234	.9545	1.048	1.382	1.448	20
50	.6926	.7214	.9601	1.042	1.386	1.444	10
44° 00'	.6947	.7193	.9657	1.036	1.390	1.440	46° 00'
10	.6967	.7173	.9713	1.030	1.394	1.435	50
20	.6988	.7153	.9770	1.024	1.398	1.431	40
30	.7009	.7133	.9827	1.018	1.402	1.427	30
40	.7030	.7112	.9884	1.012	1.406	1.423	20
50	.7050	.7092	.9942	1.006	1.410	1.418	10
45° 00'	.7071	.7071	1.000	1.000	1.414	1.414	45° 00'
	Cos	Sin	Cot	Tan	Csc	Sec	Degrees

APPENDIX B

PROJECT PROPOSAL

(Includes Pages 93 through 110)

California State College

San Bernardino

DEVELOPING A CURRICULUM FOR MOTORCYCLE TECHNOLOGY

A Project Proposal Submitted to

The Faculty of the School of Education

In Partial Fulfillment of the Requirements of the Degree of

Master of Arts

in

Education: Administration of Vocational Education Option

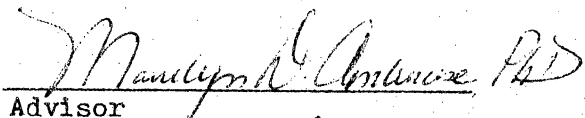
By

Ronald L. Pardee, M.A.

San Bernardino, California

1980

APPROVED BY:


Advisor


Committee Member

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DEVELOPING A CURRICULUM FOR MOTORCYCLE TECHNOLOGY

Ronald L. Pardee, M.A.

California State College, San Bernardino, 1980

Introduction

With the increased concern for energy efficient transportation, the use of motorcycles has increased to the point that there is an increased demand for service of the motorcycles already on the road. The motorcycle industry has developed motorcycles that commonly have fuel consumption rates of 50-60 MPG and the smaller models often operate at 90-100 MPG. This fuel efficiency also offers reduced exhaust emissions as compared to other forms of transportation.

At this time, there are more than three times the number of motorcycles in service, per mechanic, as there are in the auto industry.¹ With this increased demand for service, there has come an increase in demand for training. Many educational institutions are considering the implementation of new programs, but find it difficult to locate acceptable curriculum materials. Therefore, many programs are operating using materials that cannot meet the standards of the industry. This is made apparent by one of the major motorcycle manufacturers in offering an intensive one week school for instructors of motorcycle technology. During the months of July and August, 1980

1. ¹Interview with Tom Anderson, American Honda Motor Co. Inc., Gardena, California, 4 August 1978.

more than 450 secondary and post secondary instructors have enrolled in this program. This project intends to address the problem of lack of good curriculum material by developing a comprehensive curriculum package that is designed specifically for the motorcycle industry, and the training of motorcycle mechanics.

Review of Related Literature

The materials that were reviewed for this project were:

Mid-America Vocational Curriculum Consortium, Curriculum

American Motorcycle Schools, Curriculum

Riverside City College, Curriculum

Major Motorcycle Manufacturers, Curriculum, needs and texts

Educational support facilities

Motorcycle Technology textbooks

Training materials presently in use by the major manufacturers

Through this review of materials, it became even more apparent that a good curriculum for Motorcycle Technology does not exist. The most predominant format for teaching this subject matter is a list of topics to be covered. The objectives, activities, information to be specifically covered, and evaluation are all left to the discretion of the individual instructor.

The curriculums that do exist are typically nothing more than "laundry lists" that are discussed at the level of the instructor and often no consideration is given to the needs of the student or the industry.

Specific objectives for a unit of instruction may be so broad

as to cover an entire semester's program in a single paragraph.

Typical examples of objectives follow:

To train students to diagnose and repair motorcycle engines.

To develop a working knowledge of the principles and theory of the motorcycle internal combustion engine.

To provide the student with knowledge and practical application in a near industrial environment to understand the function and peculiarities of the various electrical system designs.

These are samples of what is given to an instructor with no more specific, measureable objectives mentioned. The activities to be employed in insuring that specific topics will be adequately covered are left entirely to the individual instructor.

The material from MAVCC is by far the best curriculum material reviewed, but it is not nearly as good topically, as some others.

The MAVCC curriculum is presented in a very good format, but is a suppliment to a small engine curriculum that does not adequately cover the more sophisticated motorcycle, internal combustion engine. This material also falls short in completly covering required topics in a comprehensive motorcycle technology program.

Other curriculum materials are very comprehensive in topics to be covered, but fall short in the format that will be employed in the presentation of the materials. With no stated objectives, this gives no insurance that the material will be adequately presented.

Therefore; a need exists for a complete curriculum package. One that is available to sponsoring agents so that students and districts can be more assured of a complete training program.

Statement of Objectives

The objective of this project is to develop a model curriculum for a Motorcycle Technology program. This guide will use those suitable aspects from the appropriate curriculum development resources as well as be topically accurate. It will include: suggested activities, information sheets, student assignments, evaluation instruments and keys, laboratory exercises, resource samples, and transparencies. The objective may be modified to include other materials or an evaluation of them in a test project as the need arises, time permits and with the approval/recommendation of the advisor.

Limitations

When the project is completed, its product will be limited by the availability of trained educators in this rapidly growing and changing industry, and the desire of students to enter a field that has yet to be proven in the labor market.

The distribution of this material will depend greatly upon contacts with potential users. This marketing problem may require the aid of more advanced techniques than personally available, but the potential is through a variety of sources such as articles and advertising in trade journals and direct publishing through a major outlet.

The rapidly advancing industry would require frequent updating of the original package to cover the latest equipment being produced.

The package will also be limited by the fact that it will be aimed

at the secondary and post secondary student. This limitation should be of little concern at this time, since this material is normally presented at these levels.

Another major limitation is the fact that at this time a comprehensive textbook does not exist, to go with this subject matter.

Design of the Proposed Project

- I. Research of material and its evaluation
- II. Research of proposed market
- III. Establish format of product
- IV. Request for permission to use copywrited material
- V. Develop objectives
- VI. Develop activities
- VII. Develop information sheets
- VIII. Develop assignment sheets
- IX. Develop evaluation instruments
- X. Develop evaluation instrument keys
- XI. Provide package to selected existing training facilities
for testing and evaluation
- XII. Present package to California State College, San
Bernardino, Department of Education
- XIII. Prepare for marketing

Design of the Proposed Product

The curriculum material will be developed and arranged as follows:

- I. Suggested activities

- II. Information sheets
- III. Assignment sheets
- IV. Performance skill sheets
- V. Evaluation instruments
- VI. Evaluation instrument keys
- VII. Resources

An outline of the curriculum material follows:

- I. PARTS AND LAYOUT OF MOTORCYCLE COMPONENTS
 - A. Major Components and Terms
 - 1. Proper nomenclature
 - 2. Variations in nomenclature
 - B. Standardization of Safety Equipment
- II. TOOLS AND EQUIPMENT
 - A. Hand Tools
 - 1. Identification (all basic tools)
 - 2. Special tools
 - a. Pullers
 - b. Torque wrench
 - c. Ring compressors
 - d. Stands, lifts, etc.
 - 3. Care and maintenance of tools and equipment
 - B. Measurement Instruments
 - 1. S.A.E. and metric systems
 - 2. Micrometers
 - a. Inside
 - b. Outside
 - c. Depth

3. Dial indicators
 4. Dial bore guage
 5. Vernier calipers
 - a. S.A.E.
 - b. Metric
- C. Hardware
1. Nuts, bolts, & fasteners
 2. Grade ratings
 3. S.A.E., I.S.O., & Whitworth
 4. Threads
 5. Torque ratings
- D. Testing Devices
1. Lubrication test equipment
 - a. Oil pressure
 - b. Oil temperature
 2. Engine test equipment
 - a. Compression guage
 - b. Leakdown tester (4 stroke, pressure)
 - c. Leakdown tester (2 stroke, pressure/vacuum)

III. MODERN MOTORCYCLE INTERNALCOMBUSTION ENGINE

- A. Four Stroke
1. Theory
 - a. 4 strokes, valve overlap, degreeing, etc.
 - b. Ignition
 2. Identification of engine parts
 - a. Piston, wrist pin, (pin offset)
 - b. Rings
 - c. Valves

- d. Cams, cam drives, (gears, chains, & belts)
- e. Combustion chamber configuration
- f. Crankshafts
- g. Connecting rods

3. Engine configurations

- a. Single
- b. Twin (180/360, horizontal, V)
- c. Three (120, 180/360)
- d. Four and more multi

B. Two Stroke

1. Theory

- a. 2 strokes
- b. Induction methods, characteristics
- c. Overlap, degreeing, etc.

2. Identification of parts

- a. Ports
- b. Induction control parts
- c. Rings (ring locating pins)
- d. Piston pin offset
- e. Precompression chamber
- f. Gaskets

3. Engine configurations

- a. Single
- b. Twin (180 degree)
- c. Three (120 degree)
- d. Four
- e. Unit and pre unit construction

C. Rotary Engine

1. Theory

2. Identification of parts and configuration

IV. TEXTS AND REFERENCE MATERIAL

- A. Technical Manuals
- B. Parts Manuals (Micro Fische)
- C. Flat Rate Manual
- D. Collision Guide

V. FRAME AND CHASSIS ASSEMBLY

- A. Frame Design
- B. Frame Repair
- C. Forks
- D. Shocks
- E. Tanks
- F. Fenders
- G. Handle Bars
- H. Wheels
- I. Hubs
- J. Tires

VI. BRAKES

- A. Mechanical Drum
 - 1. Principle
 - 2. Single leading shoe
 - 3. Double leading shoe
 - 4. Adjustment, service, and repair
- B. Hydraulic Principles
- C. Hydraulic Disc Brakes
 - 1. Principle
 - 2. Single disc

3. Double disc
4. Floating/stationary
5. Service and repair (pressure/vacuum bleeding)

VII. ELECTRICAL SYSTEMS

- A. Basic Principles of Electricity and Electron Theory
- B. Series Systems
- C. Parallel Systems
- D. A.C.
- E. D.C.
- F. Magnetism and Charging
- G. Diodes
- H. 1/2 Wave Charging
- I. Full Wave (stator winding configuration)
- J. 3 Phase, Full Wave (wye and delta)
- K. Voltage Regulators
 1. Zenier diode
 2. Vibrating contacts
 3. Solid state
- L. Current Limiter
- M. Charging System Checklist
- N. Starters and Generators
- O. Test Meters and their use
- P. Bench Testing
- Q. Battery
- R. Switches

VIII. IGNITION SYSTEMS

- A. D.C. Ignition
- B. A.C. Ignition
- C. Electronic Ignition
- D. Mechanics of Timing

IX. CLEANING AND PREVENTIVE MAINTANCE

- A. Methods and Purpose
- B. Materials and Tools

X. ENGINE ASSEMBLY

- A. Valves
- B. Guides
- C. Rockers
- D. Overhead Cam (single & double)
- E. Cam Drives and Cam Timing
- F. Cylinders
- G. Pistions
- H. Bearings
- I. Connecting Rods
- J. Cam Design
- K. Lubrication
- L. Seals and Gaskets

XI. CARBURETION

- A. Principles
- B. Types
 - 1. Slide controled variable venturi
 - 2. Constant velocity variable venturi
 - 3. Fixed venturi

4. Systems and ranges

- C. Fuel Injection
- D. Turbo Charging
- E. E.P.A. Standards

XII. CLUTCHS

- A. Principles
- B. Types
 - 1. Wet
 - 2. Dry
 - 3. Automatic
- C. Service, Maintance, and Repair

XIII. TRANSMISSIONS

- A. Gears and Ratios
- B. Principles of Operation
- C. Types of Shifting Mechanisims
 - 1. Drum/fork
 - 2. Camplate/fork
 - 3. Ball receiver
 - 4. Automatic
- D. Service
- E. Shifting Linkage
- F. Kickstart Mechanisms
- G. Bearings and Transmission Lubrication
- H. Types of Gears

XIV. POWER TRAINS

- A. Chains and Sprockets
 - 1. Chain design

2. Service and adjustments

3. Ratios

4. Limitations

B. Shaft Drive Units

1. Design and principles

2. Service and adjustments

3. Limitations

XV. TROUBLE SHOOTING AND DIAGNOSTIC PROCEDURES

XVI. SERVICE MANAGEMENT

A. Procedures

1. Service manager

2. Service writer

3. Mechanic

B. Systems

C. Forms

1. Repair orders

2. Warranty and insurance forms

D. New Bike Set-up

1. Pre-delivery

2. Complete service and check out

3. First service

4. Selling service

XVII. PARTS DEPARTMENT

A. Inventory Control

B. Ordering

C. Service Support

D. Customer Support

E. Sales

XVIII. MOTORCYCLE SAFETY

A. Rider Education

B. Motorcycle Safety Foundation

XIX. SCHOOL CLUBS

BIBLIOGRAPHY

American Honda Motor Co. Inc., VoTech Instructors Guide, Gardena, California: 1980.

American Motorcycle Schools, Inc., Motorcycle Mechanics Course Outline, Santa Fe Springs, California: 1978.

Anderson, Tom. American Honda Motor Co. Inc., Gardena, California.
Interview, 4 August 1978.

Holmes, Ron, and Magner, Richard. Motorcycle Science. New York: John Wiley, 1980.

Mid-America Vocational Curriculum Consortium, Inc., Motorcycle Repair Curriculum. Stillwater, Oklahoma: 1977.

Riverside City College, Motorcycle Technology Curriculum. Riverside, California: 1980.

APPENDIX C

LETTER FROM AMERICAN MOTORCYCLE SCHOOLS



5 SHOEMAKER AVE.
TAHOE SPRINGS, CA 90670
(916) 944-0122

May 4, 1981

Mr. Ron Pardee
4050 Adams
Riverside, CA 92504

RE: Crankshaft Balancing Curriculum

Dear Ron;

We have used your curriculum model dealing with crankshaft balancing in classes here at American Motorcycle Schools. The illustrations, overhead transparencies, and tests have worked very well in the classroom portion of our school. The worksheets are very helpful in our shop classes also. We have found no major fault with the technical aspects of this material. Thank you for letting us use this material.

Sincerely,

Richard J. Lytell
Head Instructor
American Motorcycle Schools

RL:np

APPENDIX D

TRANSPARENCIES

APPENDIX E

LIST OF RESOURCES

List of Resources

American Honda Motor Co. Inc.

100 W. Alondra Blvd.

Gardena, Calif. 90247

(213) 327-8280

American Motorcycle Schools Inc.

10025 Shoemaker Ave.

Santa Fe Springs, Calif. 90670

(213) 944-0631

Kawasaki Motor Corp., U.S.A.

1062 McGaw Ave.

Santa Ana, Calif. 92711

(714) 540-6500

U.S. Suzuki Motor Corporation

3251 East Imperial Highway

Brea, Calif. 92621

(714) 996-7040

BIBLIOGRAPHY

American Honda Motor Co. Inc., VoTech Instructors Guide, Gardena, California: 1980.

American Motorcycle Schools, Inc., Motorcycle Mechanics Course Outline. Santa Fe Springs, California: 1978.

Anderson, Tom. American Honda Motor Co. Inc., Gardena, California. Interview, 4 August 1978.

Holmes, Ron, and Magner, Richard. Motorcycle Science. New York: John Wiley, 1980.

Mid-America Vocational Curriculum Consortium, Inc., Motorcycle Repair Curriculum. Stillwater, Oklahoma: 1977.

Riverside City College, Motorcycle Technology Curriculum. Riverside, California: 1980.

GLOSSARY

Acceleration - the increase in velocity for a given time; e.g., the acceleration of a piston assembly from zero velocity to maximum velocity.

B.D.C. - bottom dead center.

Big End - the end of the connecting rod that is larger than the other, and attaches to the crankshaft.

Compression - the force that pushes together rather than pulls apart.

Cotangent - the trigonometric function that is represented by ratio of the length of the side adjacent to an angle divided by the length of the side opposite that angle. (i.e. $\text{COT} = \frac{\text{ADJ}}{\text{OPP}}$)

Crankshaft Boss - the part of a crankshaft that acts as a flywheel, as well as supports the crankshaft journal.

Crankwheels - the sides of a crankshaft that act as flywheels.

Counterbalancer - separate bob weights that are driven by the crankshaft but turn in the opposite direction of rotation to help balance out some vibration forces.

Deceleration - the decrease in velocity at a rate in time. To slow down.

Duration - the time that something is taking place.

Dynamic - in motion; not stationary.

Horizontal Plane - that plane which is at an angle 90 degrees from the direction of the stroke in a vertical cylinder engine.

Inertia - that force occurring in nature that tends to keep something in motion that is in motion until it is acted upon by an outside force(s), or that tends to leave at rest anything that is at rest until it is acted upon by an outside force(s).

Inertia Force - the force that tends to keep a piston moving the same way when it must change direction (T.D.C. and B.D.C.) and is calculated by the formula: $I.F. = (.0000142)(Weight)(RPM^2)(Stroke)$.

Magnitude - the amount or strength of a force.

180 Degree Twin - a crankshaft configuration when one piston is at T.D.C. when the other is at B.D.C. The combustion process of the second cylinder lags the first by 180 degrees.

Oscillate - to move back and forth.

Overlap - the time measured in degrees of crankshaft rotation when the exhaust valve has not yet closed and the intake valve has already opened, and both valves are open at the same time. Also called valve overlap.

Oversquare - a term applied to an engine that has a bigger bore diameter than its stroke length and is typically capable of reaching higher RPM ranges.

Primary Force - the force that is the result of the inertia force of the piston assembly (reciprocating components) and the centrifugal force of the crankshaft assembly (rotating components).

Reciprocate - movement back and forth in a straight line.

Rocking Couple - the force that is the result of two masses rotating about a common axis but separated axially, which will pitch the center line in one direction on one side, and the opposite direction on the opposite side.

Rotate - movement in a circular path.

Rotating Couple - an internal force in a rotating object that has offset masses, which causes uneven pressures and vibration.

Secondary Force - dynamic forces that are the product of the crank throw to rod length ratio times the primary force. Found by the formula: $S.F. = \left(\frac{T}{L} \right) (P.F.)$ where:

S.F.	= secondary force
T	= radius of the crankshaft throw
L	= length between centers of the connecting rod
P.F.	= primary force.

Static - stationary; not moving.

T.D.C. - top dead center.

Tension - the force that tends to stretch or pull apart an object.

Theta - the Greek letter θ , represents an angle. In this instance, it is the angle from the vertical plane of the engine stroke and the line from the crankshaft center to the rod pin center, when the rod is at 90 degrees to this line. One half of the included angle.

360 Degree Twin - a twin cylinder engine in which both pistons move in the same direction at the same time. The combustion process of one cylinder lags the other by 360 degrees.

Torque - a turning or twisting force. A force producing rotation.

Undersquare - a bore to stroke relationship where the stroke is longer than the bore. Typically lower RPM engines that produce greater torque than an oversquare design.

Valve Overlap - see overlap.

Velocity - the time rate of linear motion (e.g. feet per second).

Vertical Plane - direction of engine stroke.